Worldwide Trends in Gold Exploration

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Foreword

The economics of gold exploration and production have assumed increasing importance in the period since 1969 when the price of gold began to be set by a free market. Policy-makers in both government and industry need data and analysis of the price and cost conditions under which it becomes worthwhile to invest in exploration activities. In this paper, the authors assess the outlook for gold exploration during the 1990s, including dynamic growth factors, the relationship between discovery and depletion, and future price possibilities. It is particularly instructive to compare the circumstances which determine the potential for exploration as a wealth-creating activity in Australia, Brazil and Canada.

The Centre for Resource Studies offers this series of working papers for information and discussion, in an attempt to improve the understanding of the conditions and issues facing the Canadian mineral industry, to assist in the formulation of policy, and to encourage research in mineral policy. Opinions expressed are those of the authors and do not necessarily represent the views of the Centre or its sponsors.

Moira Jackson
Centre for Resource Studies

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- The examination of trends in gold supply, and the economic performance of gold exploration in Canada comes under the auspices of the Centre for Resource Studies. Michel Bilodeau and Bill Orme provided the required computer modeling and analysis.

Executive Summary

1. The paper examines worldwide trends in the economic environment for gold exploration. Particular attention is given to the post-1969 era of free-market gold. The purpose of this analysis is to assess the economic prospects for gold exploration during the 1990s.

2. The great gold rushes of the past three centuries have caused world gold production to surge through a series of long waves which are characterized by ever-ascending peaks and decreasing amplitudes. The secular pattern of gold supply provides a useful perspective for understanding the world-wide gold rush which has occurred during the last two decades.

3. Record levels of bullion production in Brazil, the United States, Australia, and the rest of the world during the 1986-90 period, and close to peak output in Canada, were only partially offset by a 30-year low in South Africa. Consequently, we are presently riding the crest of an unprecedented wave of gold mine production, formed as the result of worldwide discovery and development during the 1980s.

4. The economic environment for gold exploration is shaped by three interrelated market variables – the price of gold, exploration expenditures, and bullion production. Each of these in turn has established an all-time Western World record during the past decade as follows:

   - international price of $971 per ounce[1] in 1980;
   - exploration expenditures of $2.4 billion in 1987;
   - mine production of 1,734 tonnes in 1990.

5. The economic outlook for gold exploration during the 1990s is positive. An examination of the relationship between gold discovered and gold depleted in the Western World demonstrates that the peak levels of gold exploration during the 1980s are unlikely to result in an oversupply of gold in the years ahead. The all-time production record set in 1990 will likely stand for a long time. Thus, the future price of gold can be expected to at least maintain its historical average of above $400 per ounce.

6. While the overall market forces provide encouragement for gold exploration, they are not in themselves sufficient to justify investment. For this purpose, a more specific assessment of the economics of exploring for gold is required. We need to know to what extent the search for gold deposits represents an economic investment and, more intrinsically, a wealth-creating endeavour.

7. The following historical record in three of the world's major gold mining nations provides the basis for assessing and comparing the economics of exploring for new primary gold deposits:

   - Australia, 1969-86, $526 million of exploration expenditures resulting in the discovery of 61 possible economic deposits;

[1] All money values are expressed in constant 1990 United States dollars.

- Brazil, 1969-88, exploration expenditures of $388 million resulting in 34 possible economic gold discoveries;

- Canada, 1969-88, $2,899 million of exploration expenditures resulting in the discovery of 134 possible economic deposits.

8. For each country, the historical experience is evaluated in the context of current economic and technological outlook conditions. The procedure applied provides objective and relevant appraisals for strategic planning purposes. The conditions assumed include an international gold price of $400 per ounce and a 10-percent cost of capital.

9. Bottom-line expected values demonstrate that gold exploration in Australia and Brazil is a wealth-creating activity, offering potential to increase substantially the economic surplus available to society. For example, the expected rate of return on exploration investment is 18 percent in Australia and 19 percent in Brazil. Conversely, gold exploration in Canada is found to be a decidedly uneconomic activity overall, offering an expected rate of return of only 4 percent relative to the 10-percent cost-of-capital margin.

10. The negative exploration performance in Canada is mainly attributable to very high discovery costs. The average undiscounted exploration expenditure per economic discovery in Canada ($67 million) is found to be about four times the average discovery costs in Australia and Brazil ($13 million and $17 million respectively).

11. Time trends in exploration performance are also examined, comparing the economics of gold exploration during the 1969-82 interval with the more recent gold rush from 1983. The following changes are found to have occurred.

    - In general, there appears to be a falling off in economic performance with time.

    - The economic potential of gold exploration in Australia has held up relatively well with time, a sharp improvement in typical discovery costs tending to offset a strong decline in the average size of the economic deposits found.

    - The reliability of the changes assessed in Brazil is limited by the small sample size of exploration experience in the 1969-82 interval. Discovery of the four largest economic gold deposits at this time caused a steep fall in the economic potential of Brazilian gold exploration to near the breakeven point during 1983-88.

    - In Canada, the economic potential of gold exploration falls from the breakeven point in 1969-82 to a hopelessly uneconomic situation during the 1983-88 interval. This ruinous change is caused by a three-fold increase in average discovery costs, from $34 million to $106 million.

12. Finally, a related question is addressed in each case – what minimum acceptable, or breakeven, price of gold would be required to economically justify the extraordinarily high levels of investment in gold exploration in recent years? For the post-1969 study period, gold exploration in Brazil is found to have the most competitive breakeven price requirement ($291 per ounce). However, Australia's position improves with time, requiring the lowest gold price during the most recent interval ($343 per ounce). The breakeven price findings for gold exploration in Canada, $508 per ounce for the 1969-88 period and $665 per ounce for the 1983-88 interval, once more point to the uneconomic, wealth-destroying character of this endeavour from a national perspective.

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1. Introduction

The paper examines worldwide trends in gold exploration, focusing on the post-1969 era of free-market gold. The purpose of this analysis is to assess the economic prospects for gold exploration during the 1990s.

We start out in Chapter 2 by setting the modern free-market era in the context of the secular waves of gold discovery and production which have swept across the world during the past three centuries. Particular attention is given to the supply patterns of five major gold producers: Brazil, the United States, Australia, South Africa, and Canada.

Chapter 3 analyzes changes in three leading variables which shape the economic environment for gold exploration:

- the international price of gold;
- gold mine production;
- gold exploration expenditures.

Time trends and relationships among these variables during the 1969-90 period are examined with specific reference to the five major producing nations.

Chapter 4 investigates implications of the historical price, production, and exploration expenditure footprints for gold exploration during the 1990s. Consideration is given to time lags in the gold supply process, the relationship between discovery and depletion, dynamic growth factors, and future gold price possibilities.

Finally, in the context of this worldwide environment, Chapter 5 addresses an essential question: To what extent is gold exploration an economic investment and, more intrinsically, a wealth-creating activity? Empirical assessments of the potential of gold exploration for wealth creation in Australia, Brazil, and Canada are presented based on experience documented during the modern free-market era.

2. Secular Patterns of Discovery and Production

This chapter briefly reviews the great gold rushes of the past three centuries and their impact on world gold supply. The long waves of discovery and production provide a useful perspective for the global gold rush which has taken place during the last two decades. In addition, an understanding of the secular pattern of gold supply helps define the present economic position of gold exploration as we enter the 1990s.

Gold Price

Since the intrinsic value of gold has always provided the basic incentive to search for unknown deposits, we start off with a short survey of historical gold prices.

The uncertainty of the future price of gold is of paramount importance in evaluating the economics of gold exploration nowadays. Yet, as Green (1987) points out, it is a relatively new concern. The traditional reputation of gold was founded on the very certainty of its price. It was the standard against which other prices were compared.

The sterling price of £3.17.10½ d. per standard troy ounce (22-carat gold, equivalent to £4.4.11½ d. per fine ounce), established in 1717 by Sir Isaac Newton as Master of the Mint, lasted for over 200 years with only a few minor deviations. Similarly, in other currencies, the nominal gold price was fixed under various forms of gold standard until the early 1930s. Thus, the purchasing power of gold rose and fell solely as a function of general deflationary and inflationary trends in the world economy. Particularly in times of depression, the fixed gold price provided a strong incentive for individual prospectors, sparking the great nineteenth-century gold rushes.

For over 100 years, the United States dollar value of gold was fixed. Then, in 1934, the United States government devalued the dollar by increasing the nominal bullion price from the US $20.67 price, which had prevailed since 1879, to US $35 per ounce. This revaluation had a highly stimulating effect on mine production throughout the world. Following the initial impetus, however, the fixed nominal price combined with cost inflation through the 1950s and 1960s to force a steady decline in gold mining activity.

By the 1960s, several factors had reduced the world's confidence in the ability of the United States to redeem its currency and debt in gold. Consequently, a "two-tier" gold price system was established in 1968. The official US bullion price was thereby restricted to monetary transactions involving government-owned gold, and an open-market gold price, free to fluctuate with supply and demand, was recognized for other transactions. Subsequently, the flow of gold from the US Treasury to other governments was checked in 1971 by a presidential order ending the convertibility of US dollars into gold. Since that time, the free market has flourished.

Global Trends

Approximately 117,000 tonnes of bullion have been recovered from gold deposits to 1990.[2] Of this total, about 16,000 tonnes were produced prior to 1700. As described by Handley (1990), gold was initially most abundant in Egypt, mined by the pharaohs more than 5,000 years ago from alluvial deposits along the Nile. The search for gold soon extended southwards into Nubia and down the east coast of Africa. The entire Middle East was an area of sophisticated gold mining and fabrication during the period 3000-2000 BC. The discovery and production process spread into Europe and Asia during the Iron Age (1200-50 BC) and the Roman Empire (50 BC-300 AD). Spain and Russia were the leading gold miners at this time, followed later by China and Africa. A major fall in production occurred in the Dark Ages (300-1000 AD), recovering only slowly through the Middle Ages (1000-1500 AD). Spanish gold, plundered from South America in the sixteenth century, and subsequent mining, with Colombia as the largest contributor, represented a major new source of supply.

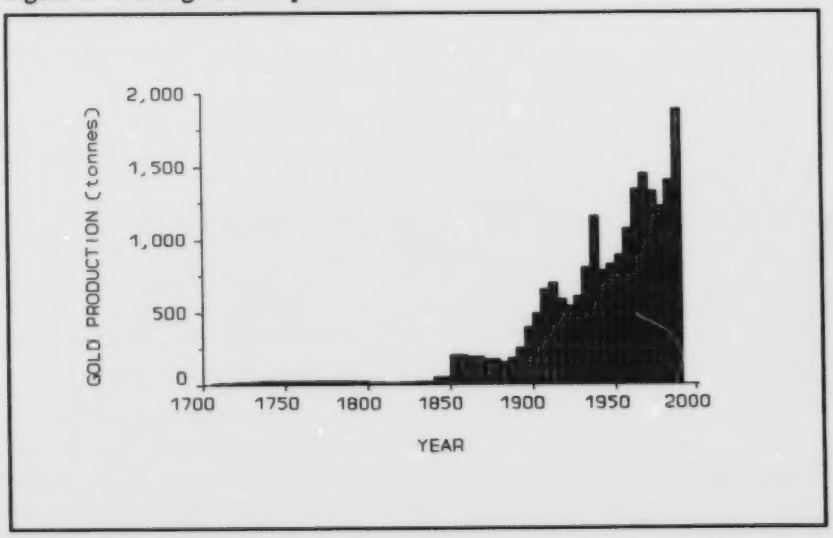
Trends in the annual rate of world production since 1700 are illustrated in Figure 1.[3] A total of 3,000 tonnes of gold were mined from 1700 to 1850, Brazil and Russia being the major sources. The sudden expansion of production from the middle of the nineteenth century followed a series of discoveries, unprecedented in both size and geographical extent, including

- California goldfields in 1848;
- New South Wales and Victoria in 1851-52;
- the Witwatersrand in 1886;
- Cripple Creek in 1891;
- Kalgoorlie's "golden mile" in 1893;
- the Klondike in 1896.

[2] More than 95 percent of this total is estimated to be present in above-ground stocks. These holdings include government bullion reserves, gold in jewellery, privately held gold coin and bars, and gold contained in other fabricated products.

[3] The histograms presented in Figures 1-7 plot the averages of annual gold mine production for 5-year intervals up to 1986-90. Mine production statistics since the 1960s have been taken from the annual reviews published by Consolidated Gold Fields, considered the most authoritative source of gold supply and demand information. See, for example, Stewart Murray *et al*, *Gold 1991*, Gold Fields Mineral Services, May 1991. Earlier statistics and the cumulative totals have been compiled from a wide range of sources which are cited in the reference list.

Figure 1. World gold mine production



In the short span of 50 years to the turn of the century, more gold was recovered from the earth than in the preceding 5,000 years.

The following breakdowns of total world gold supply to 1990 are also revealing:

- three-quarters mined this century;
- one-half mined since the end of World War II;
- more than one-quarter mined during the post-1969 free-market era.

Figure 1 shows that the growth in world gold production has tended to surge through a series of waves which are characterized by ever-ascending peaks and decreasing amplitudes. The peaks comprise

- 30 tonnes per year in 1781-85;[4]
- 200 tonnes per year in 1851-55;
- 695 tonnes per year in 1911-15;
- 1,157 tonnes per year in 1936-40;
- 1,448 tonnes per year in 1966-70.

[4] Knowledge about the distribution of eighteenth-century mine output is sketchy. This initial peak could have occurred as early as 1751-55.

Average annual gold production of 1,885 tonnes for the 1986-90 interval is clearly an all-time high. What is uncertain as yet is whether this record output represents the peak of the most recent wave.

As summarized in Table 1, South Africa has produced 37 percent of total world output, followed by the United States (10 percent), Australia and Canada (6 percent each), and Brazil (2 percent). A diverse group of other countries produced the remaining 39 percent, most notably the former Soviet Union, which accounts for 14 percent of total output.

Table 1. Gold mine production to 1990

Region	Total Production to 1990 (tonnes)	Share of World Total (percent)
Australia	6,886	6
Brazil	2,359	2
Canada	7,585	6
South Africa	43,257	37
United States	11,233	10
Rest of the world	46,079	39
World	117,399	100

While controlled by overall market forces, the secular distribution of worldwide gold production shown in Figure 1 is nevertheless a composite of distinct patterns of discovery and depletion which have characterized the major gold mining nations.

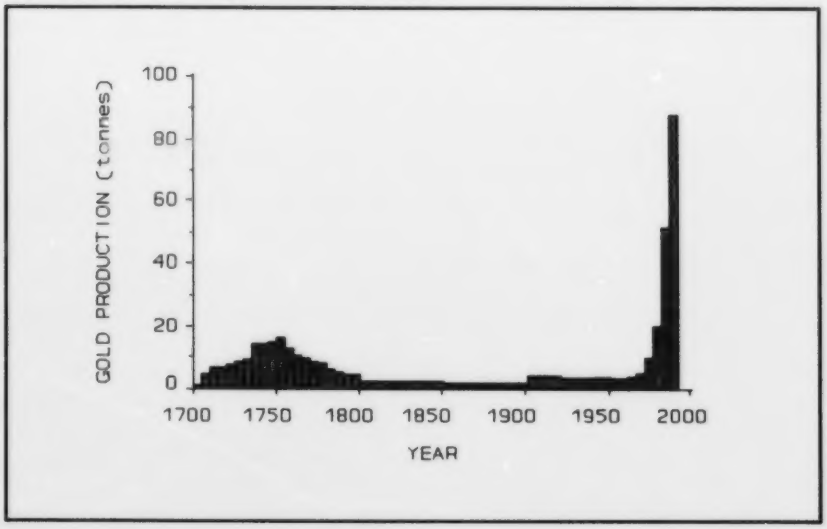
We now take a more specific look at the make-up of production from each of the major gold miners in the Western World, in order of their ascendancy: Brazil, the United States, Australia, South Africa, and Canada, followed by a brief outline of output in the rest of the world.

Brazil

For 300 years, Brazil has been a major force in the international gold market. During the period 1700-1850, Brazil was the number-one producer of gold in the world.

As shown in Figure 2, Brazilian gold production (2,359 tonnes to 1990) exhibited sustained growth in the first half of the 18th century, reaching its highest point at an average annual rate of 16 tonnes during the period 1751-55. Brazil's ascendancy resulted from the discovery of important alluvial and superficial deposits of gold, particularly in a region around Ouro Preto now referred to as the Quadrilatero Ferrifero (Iron Quadrangle) of Minas Gerais. Then followed a period of declining production to an average of 4.5 tonnes of gold per year by the end of the century. This prominent 18th-century gold cycle is referred to in Brazilian literature as the *Seculo do Ouro*, or *Century of Gold*. Although production decreased somewhat, the importance of Brazil as a world gold producer continued through the first half of the 19th century. Thereafter, a further drop in domestic production coupled with large discoveries elsewhere resulted in a much diminished role for Brazil as an international force.

Figure 2. Gold mine production in Brazil



Morro Velho was the country's dominant producer from the 1830s to the 1970s. The discovery of the Serra Pelada deposit in the late 1970s sparked a remarkable upsurge in Brazilian gold output from an annual average of approximately 5 tonnes in 1966-70 to a record high of 87 tonnes per year in 1986-90.[5] Most of this growth is attributable to the work of several hundred thousand

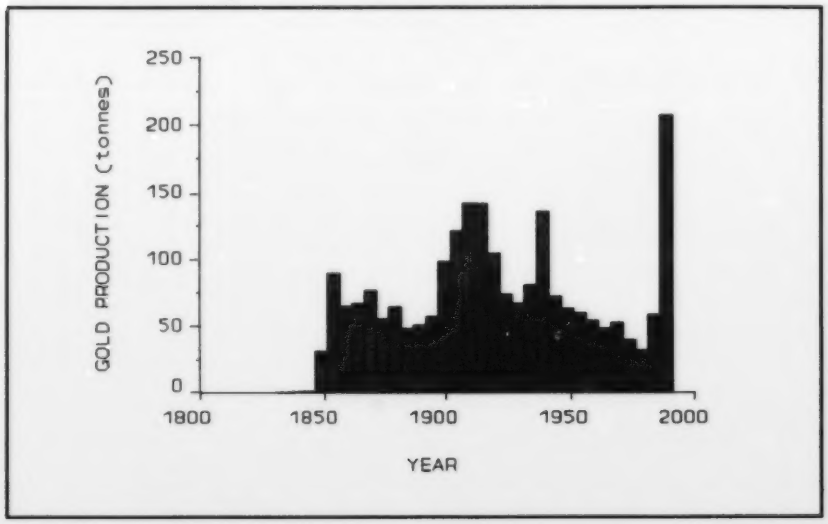
[5] Unofficial estimates of total production provided by Departamento da Produção Mineral, Brasília.

garimpeiros (prospectors), who are mainly active in the Amazon Basin. In addition, international and Brazilian mining companies have become increasingly prominent with the development of major deposits such as Crixás, Fazenda Brasileiro, and Morro do Ouro.

United States

The time distribution of gold mine production in the United States, totalling approximately 11,200 tonnes, is presented in Figure 3.

Figure 3. Gold mine production in the United States



Modest quantities of gold were produced from small-scale placers and weathered bedrock in the Appalachian region of the eastern U.S. in the early 18th century. With the news of the discovery of gold at Sutter's mill in northern California in 1848, 100,000 men headed west. The California deposits proved to be extremely rich, and production climbed to an average of 89 tonnes per year during the 1851-55 period, representing about 45 percent of world output.

By the late 1850s, the smaller claims had been worked out and many of the "49ers" began to move into the interior of the western United States in search of new goldfields. This migration resulted in the opening up of the Comstock Lode and Tonopah districts in Nevada, the Clear Creek deposit in Colorado, and numerous other discoveries, mostly in Idaho and Montana, during the 1860s.

Up to the 1870s, most gold production came from easily mined placer deposits, but from then on underground mining of lode deposits began to play an important role, especially in Colorado. The Homestake mine in South Dakota started production in 1877.

From 1890, a notable climb in annual gold production occurred (Figure 3), to a record level of 142 tonnes annually in 1906-10. This rise was the result of the Cripple Creek discovery in 1891, placer production from the Alaskan gold rush, together with extensive development of other deposits discovered in the west during the 1860s and 1870s.

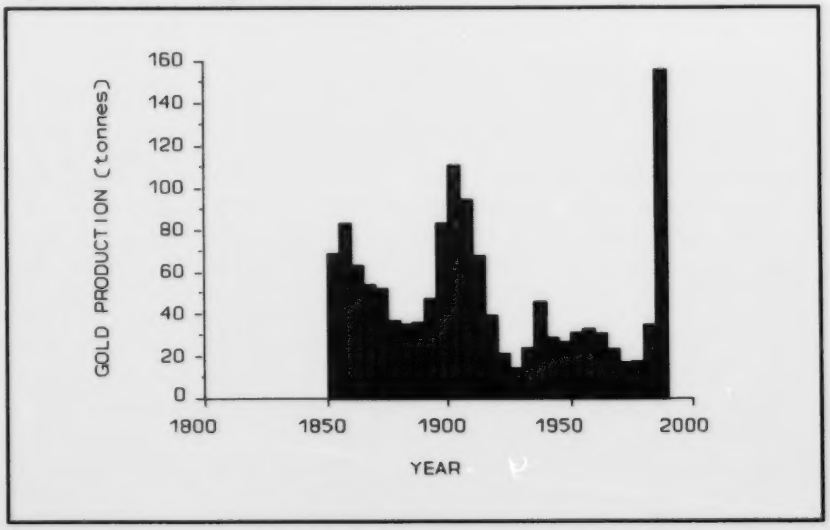
A lengthy decline in gold mine production followed, sharply but temporarily arrested in the late 1930s by the effects of the 1934 increase in gold price from $20.67 to $35 per ounce. By the 1960s, the only significant gold mine remaining was Homestake, although appreciable amounts of by-product gold were recovered from the porphyry-copper mines.

The development of the Carlin and Cortez deposits in Nevada led the way into the modern era of gold mining in the southwestern United States. Thirty new gold mines have opened in Nevada alone during the last few years. These producers are mainly very low-grade epithermal deposits of disseminated gold that can be mined as open pits, with ore which is often amenable to heap-leaching technology developed in the late 1970s. These new gold mining opportunities, mainly in Nevada, California, and Montana, have raised gold production in the United States from an average of 32 tonnes per year in 1976-80 to a new all-time record of 207 tonnes annually in 1986-90.

Australia

About 6,900 tonnes of bullion have been recovered from Australian gold deposits to date. The pattern of production is shown in Figure 4.

Figure 4. Gold mine production in Australia



Gold was initially discovered in eastern Australia in the 1820s. However, it was not until 1851 that the significance of these rich alluvial deposits was appreciated through the efforts of Edward Hargraves in the Bathurst district of New South Wales, and James Esmond at Clunes in Victoria, precipitating Australia's first gold rushes (Woodall, 1975 and 1990). It is interesting to note that both men gained their experience on the California gold diggings.

The alluvial gold finds were followed in 1852 by the discovery of "deep lead" alluvials, first at Ballarat in Victoria, and then on other goldfields in Victoria and New South Wales. Small underground gold mines were established at these locations. The main deposits of lode gold were at Bendigo in Victoria, where more than a thousand companies developed mines to work a field only 11 km long by 3 km wide. These mining activities lifted Australian gold production to an average of 84 tonnes per year during 1856-60.

Depletion and a consequent decline in production followed this peak period. At the same time, the search for gold deposits spread anti-clockwise around Australia to Queensland in the 1860s and 1870s, and then on to the Northern Territory and Western Australia. Spectacular discoveries of gold in the Kalgoorlie region of Western Australia in 1893 greatly accelerated the flow of mining capital to Australia. Between 1894 and 1896, 690 Western Australian gold mining companies were floated in London. Resulting from this activity, record Australian production averaging 112 tonnes per year was achieved during the 1901-05 period.

Gold mining in Australia plummeted during and after the 1914-18 war (Figure 4). While a rise in production followed the revaluation of gold in the early 1930s, gold mining declined once again after the second world war as the fixed gold price was squeezed by rising costs. Only four significant Australian gold mines survived to the mid-1970s.

The gold mining boom of the mid-1980s, in Australia as elsewhere, was triggered by the high gold prices of the early 1980s. The eastern goldfields region of Western Australia, centred in Kalgoorlie and over 500 km long, became the site of hundreds of gold mines, mills, and development projects. There was also notable expansion in Queensland and the Northern Territory. Consequently, average annual gold mine production in Australia rose from only 18 tonnes in 1976-80 to an all-time high of 158 tonnes in 1986-90.

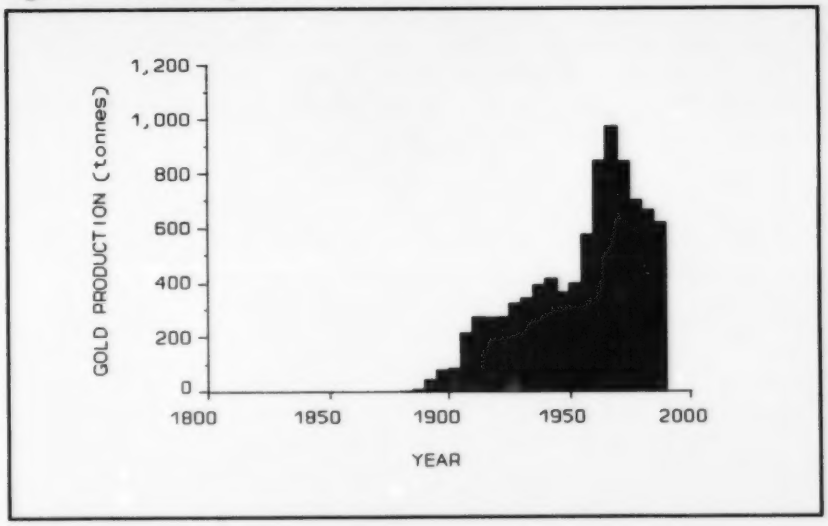
South Africa

Approximately 43,000 tonnes of gold have been mined in South Africa, representing 37 percent of all the bullion produced in the world. The time distribution of this unique contribution is illustrated in Figure 5.

The first discovery and small-scale production of gold in South Africa occurred at Pilgrims Rest and Barberton in the eastern Transvaal during the 1870s and early-1880s. These activities were soon overshadowed by the singular event in the history of world gold mining – the discovery of the Main Reef of the Witwatersrand Basin by George Harrison (who had previously worked on the Australian goldfields) in 1886.

Full-scale mining on the Central Rand began in 1887 and accelerated during the 1890s with the introduction of the cyanide process for treating

Figure 5. Gold mine production in South Africa



sulphide ores. Production increased to an average of 78 tonnes per year during 1896-1900. Gold mining on the West Rand and East Rand followed the extension of the outcrop of the Main Reef from the Central Rand. From 1886 to 1930, development and production in the Witwatersrand Basin were concentrated on mines in these three fields, lying in a more or less continuous arc from Randfontein, 30 km northwest of Johannesburg, to Nigel 50 km to its southeast. Gold production rose steadily to an average of 321 tonnes per year during the 1926-30 period (Antrobus, 1986).

The increased gold price in 1934 coupled with advances in exploration geophysics during the 1930s resulted in the discovery of gold-bearing reefs on the West Wits Line (also known as the Far West Rand) southwest of Randfontein and, in due course, the establishment of several major new mines. Gold production from the Klerksdorp field was also brought on stream at this time.

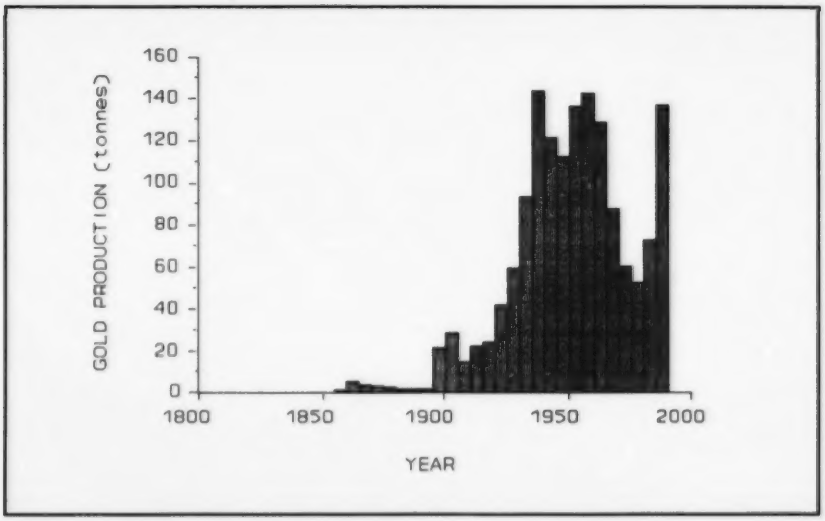
It was not until the late 1940s and early 1950s that the Orange Free State field was discovered and development began. The last of the major areas to be brought into production on the Witwatersrand was the Evander (or Far East Rand) field, about 110 km southeast of Johannesburg, which was discovered and developed in the late 1950s and early 1960s.

As the result of these discoveries around the rim of the Basin, and the subsequent development of many new gold mines, gold production in South Africa following the second world war climbed dramatically, culminating in record output of 970 tonnes per year in 1966-70 (Figure 5). Since that time, gold exploration and development on the Witwatersrand have concentrated on down-dip extensions of the reefs being mined, the potential for mining other reefs on lease areas covered by existing operations, and on-strike extensions of reefs to close the "gaps" between the known goldfields. Despite high levels of investment in mine development, South African output has steadily declined, averaging 616 tonnes per year in 1986-90. Production levels had not been so low since 1956-60, when annual mine output averaged 573 tonnes.

Canada

Canada has yielded approximately 7,600 tonnes of gold. Of the five major producers, Canada was the last to attract international attention. The pattern of production is presented in Figure 6.

Figure 6. Gold mine production in Canada



The first recorded discovery of placer gold in Canada was in the Eastern Townships of Québec during the 1830s. Saddle reef gold deposits were found in Nova Scotia in 1862. More significant production resulted from placer deposits found in British Columbia, on the Fraser River in 1858 and in the Cariboo district during the 1860s. Prospectors and miners who had drifted northward following the California gold rush played a role in these discoveries. Despite these activities, Canadian production averaged only 2 to 3 tonnes per year until the mid-1890s.

In 1896, the Klondike gold rush began with the discovery of gold on the banks of a tributary of the Yukon River. Coming as it did in the midst of a world depression, thousands took to the trail. Production peaked in 1901-05 when an average of 29 tonnes of gold per year were recovered from creeks in the Klondike area. Once the easily accessible gravels had been exhausted, output rapidly declined.

A great expansion of mining in eastern Canada was associated with the discovery of silver deposits at Cobalt, Ontario, in 1903. The prospectors involved and the wealth created at Cobalt formed the nucleus for development of gold mining in Ontario and Québec.

The Porcupine goldfield was found in 1908 and rapidly brought on stream with the establishment of the Dome and Hollinger mines, both of which became world-class producers. Following success at Porcupine, exploration interest turned to Kirkland Lake which quickly developed after 1915.

In Québec, production of gold on a significant scale commenced in 1927 as a by-product from the Horne copper mine at Noranda. The increase in the gold price in the early 1930s stimulated the discovery and development of major new mines at Malartic, Cadillac, and Val d'Or. Many gold deposits were found elsewhere in Canada at this time, most notably in the Red Lake area of northwestern Ontario, and at Yellowknife in the Northwest Territories. Development of these camps extended into the 1940s.

Record gold production of 143 tonnes per year was attained in 1936-40. More than 100 gold mines were operating in Canada at this time. Production rates were maintained at over 100 tonnes per year until the mid-1960s, but after that output declined rapidly to an average of 53 tonnes per year during the 1976-80 period. By that time, only 17 gold mines were operating.

In contrast to the United States and Australia, where expansion during the 1980s has come mainly from open-pit mines, the gold boom in Canada is associated with hard-rock underground mines. Canadian gold production increased from 53 tonnes annually in 1976-80 to 136 tonnes per year in 1986-90, close to the 1936-40 peak. The dominant features of this growth have been the three major new mines which were brought on stream at Hemlo in northwestern Ontario, new developments and expansions in the known gold mining camps, chiefly in Ontario and Québec, and the Lupin mine in the arctic.

Rest of the World

Although economic concentrations of gold in the earth's crust are rare, the geographical distribution of gold production is remarkably extensive. While attention to this point has focused on five major gold mining nations, 39 percent of world production to 1990 has originated elsewhere (Table 1).

This important category includes most notably the Commonwealth of Independent States (C.I.S., formerly the Soviet Union, including Russia), a major producer in its own right, representing 14 percent of cumulative world supply.[6] The remaining one-quarter share is divided among a diverse group of nations. Some of these, including China, Colombia, Ghana, and Zimbabwe, like the C.I.S., are legendary sources. Others – the Philippines, Papua New Guinea, and Chile, for instance – have gained prominence in the modern free-market era.

The collective time series of gold output in the rest of the world since 1700, illustrated in Figure 7, is characterized by a generally rising trend, with an accelerating growth rate since the 1960s. Peak production, averaging 682 tonnes of bullion per year, was attained during the most recent 1986-90 interval. The geographic breakdown of this record output is shown in Table 2. Future growth potential is perhaps greatest in Papua New Guinea, as the world-class Porgera, Misima, and Lihir discoveries are developed to their full potential during the 1990s.

[6] No CIS production statistics have been released since 1929. Estimates, based on gold sales, are therefore speculative, incorporating assumptions about both mine production and changes in Soviet central bank gold reserves.

Figure 7. Gold mine production in the rest of the world

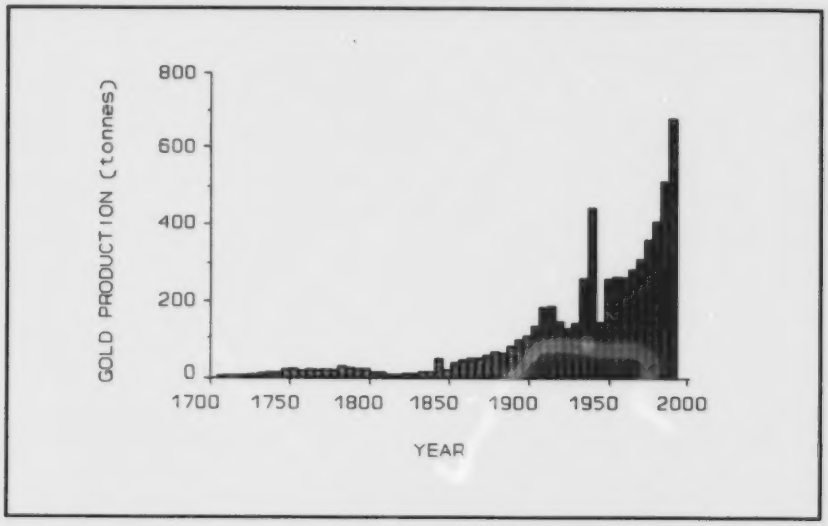


Table 2. Gold mine production in the rest of the world, 1986-90

Country	Average Annual Production 1986-90 (tonnes)
Commonwealth of Independent States	275.4
China	79.2
Philippines	38.5
Papua New Guinea	34.8
Colombia	31.4
Chile	25.4
Venezuela	16.5
Zimbabwe	15.5
Ghana	13.6
Japan	13.0
Peru	11.8
Indonesia	11.4
Zaire	11.1
North Korea	10.0[e]
Mexico	9.8
Ecuador	8.7
Bolivia	8.6
Other countries	67.0
Total	681.7

Source: Murray *et al* (1991).
[e] estimate

Further consideration is now given to gold mining trends for the sixth major producer, the recently reconstituted Soviet Union.

Commonwealth of Independent States

Bullion production from the vast region now designated the C.I.S., estimated to total approximately 16,500 tonnes, can be traced back to auriferous stream gravels in Armenia worked since Neolithic times (prior to 3500 BC). These placer gold sources were sought by Jason and his Argonauts circa 1300 BC and by Alexander the Great in 33 BC (Green, 1986).

A significant lode gold deposit in the Ural Mountains, discovered in 1744, was systematically mined for the next 40 years. More discoveries followed so that, according to Green, prior to the great California and Australia gold rushes of the mid-nineteenth century, Russia was the foremost gold miner, yielding in the order of 60 percent of all the world's gold.

Gold production continued to rise to about 45 tonnes annually by the mid-1880s (when the Witwatersrand started up), and 60 tonnes per year by 1914. A major push to further expand Soviet gold mining came under Stalin in the late 1920s with the objective of promoting population growth and industrial development and, thereby, asserting sovereignty in the far eastern barren lands of Siberia. Output rose accordingly to more than 100 tonnes annually during the 1930s. From then on, most of the Soviet Union's gold output has been from alluvial deposits in a region of Siberia which embraces the Lena and Aldan rivers, the province of Magadan, and the Kamchatka and Aldan peninsulas which extend into the Bering Sea opposite Alaska (Green, 1986).[7]

[7] These Siberian placers are related geologically to the Alaskan and Klondike goldfields.

The predominance of the Siberian fields has been rivalled during the past twenty years by a major lode gold mining complex at Muruntau in the central Asian province of Uzbekistan which started up in 1969. Today Muruntau, comprising a huge open pit and a separate underground operation, is one of the largest gold mines in the world with an annual capacity that may be as high as 80 tonnes (Green, 1986).

CIS bullion output is estimated to have increased from 150 tonnes per year in the 1960s to a plateau of 250 to 300 tonnes annually during the 1970s and 1980s. This expansion, led by Muruntau, has been augmented by development of the high-grade Zod deposit in the mountains of Armenia, not far from the site of the ancient placer workings, and by increased by-product gold recovery from base metal mines.

A more informed picture of CIS gold supply is emerging since 1990 as the former Soviet Union opens up after decades of secrecy. According to some sources, the CIS gold mines are not producing 250 to 300 tonnes per year as has traditionally been surmised. Annual output may be no higher than 200 tonnes (Hildebrandt, 1991). Moreover, there has been a substantial downward revision of CIS central bank gold reserves, conventionally thought to be in the order of 2,000 to 3,000 tonnes. A statement by a senior Soviet government official at an IMF/World Bank meeting in late 1991 placed these reserves at only 390 tonnes.

Difficult as it is to estimate historical levels of production from the C.I.S., the future prospects for gold mining are of course even more uncertain. The following factors indicate that the CIS gold industry is heading into a troubled time:

- reports by recent visitors highlight technical problems, including poor-quality equipment, inadequate maintenance, lack of spare parts, poor labour relations, environmental problems, inadequate infrastructure and, consequently, poor productivity;

- as much as 70 percent of current CIS gold production comes from alluvial deposits which account for only 20 percent of identified reserves. Production from established mining districts seems to have peaked. Exploration success does not appear to be replacing depleted reserves. Expansion of production from lode deposits will require major investment;

- more generally, this part of the world has entered a period of political and economic chaos reflected by the structural disintegration of the former Soviet Union, an outmoded and deteriorating capital base, a 25-35 percent drop in total output in 1991, and run-away inflation of 250-350 percent per year (MacFarlane, 1991). This deterioration is unlikely to be easily or quickly reversed.

Therefore, a significant decrease in CIS gold output during the 1990s can be anticipated.

Summing Up

Record levels of bullion production in Brazil, the United States, Australia, and the rest of the world during the 1986-90 period, and close to peak output in Canada, were only partially offset by a 30-year low in South Africa. Consequently, we are presently riding the crest of an unprecedented wave of gold production, formed as the result of worldwide discovery and development during the 1980s.

What are the chances of this historical peak being sustained and surpassed as we look ahead through the 1990s to the turn of the century and beyond? To address this issue and its implications for gold exploration, some of the underlying causes of the record output now will be more closely examined.

3. Trends During the Free-Market Era

In this chapter, we consider changes in three leading variables which shape the economic environment for gold exploration:

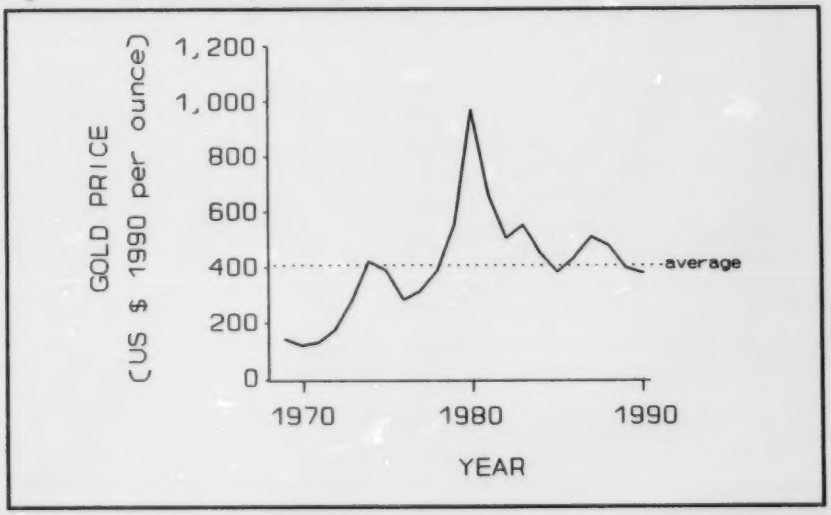
- international price;
- mine production;
- exploration expenditures.[8]

Time trends and relationships among these variables in the Western World[9] market from 1969 to 1990 are examined. Particular attention again is given to the comparative position of five major gold producers: Australia, Brazil, Canada, South Africa, and the United States.

International Price

As outlined in Chapter 2, the international price of gold was fixed in one form or another until 1968. Thus, for present-day exploration planning purposes, the relevant historical gold price timeframe starts circa 1969. Figure 8 presents average annual gold prices for the 1969-90 period.[10] The price of gold[11] has risen on average at 5 percent per year during this free-market era, comprising a 19-percent annual increase from $146 per ounce in 1969 to a pronounced peak of $971 per ounce in 1980. This was followed by a decline, averaging 9 percent per year, to $384 per ounce in 1990.

Figure 8. International price of gold



[8] By focusing on primary, or new mine, gold supply we are ignoring both demand factors affecting the gold market and secondary supply factors. While annual mine production is small compared with the large gold holdings in central bank reserves, it has been shown that, despite occasional periods of active buying and selling, central bank holdings have been virtually constant since the 1950s (Hildebrandt, 1991).

[9] This geographical restriction is necessitated by our ignorance about exploration expenditures elsewhere. While "Western World" is somewhat of a misnomer, the intent is to exclude second-world countries which have or which had, for most of the 1969-90 period, centrally planned economies.

[10] Details are given in Table 8, Appendix I.

[11] From here on, money values are expressed in constant 1990 United States dollars.

The transition of gold from its traditional monetary role to a form of investment took several years. As shown in Figure 8, the bullion price was quite stable through 1971 and thereafter began a slow upward trend which gathered momentum to 1974. Prices declined in 1974-77 and then developed a major accelerating rise to the 1980 "spike". Since then, the price of gold mainly has fallen and by 1990 had reached a level equivalent to only 40 percent of the price attained in 1980, on a par with the earlier 1974-75 peak.

The reasons for historical gold price fluctuations and trends are not easy to unravel. The fundamental supply and demand factors which explain all mineral commodity markets are, in the case of gold, overlaid by a complex set of economic, sociological, and political intangibles. The 1970s witnessed an extraordinary increase in investor demand for gold. The initial 1971-74 rise was stimulated by the commodity price boom, the first oil price shock, rising inflation rates, the weakening US dollar, and uncertainties concerning interest rates. The excessive price rise in 1976-80 was encouraged by the international political situation, including the OPEC oil embargo and the crisis in Iran, negative real interest rates, the rising trend to double-digit inflation rates, and immoderate speculation on futures exchanges, including the move of the Hunt brothers into silver.

The decline in bullion prices since 1980 is attributable mainly to the sharp rise and sustained level of real interest rates, relatively low inflation, and the unusual strength of the US dollar. Thus, some of the underlying economic conditions which had fueled the increase in investor demand for bullion during the 1970s reversed themselves. The price no longer appears to move in response to political events. Rising petroleum prices in late 1990 associated with the Mideast crisis, and the outbreak of war with Iraq in early 1991, did not have the uplifting impact on the gold price which would have been anticipated on the basis of market experience during the 1970s. Also, the prospect of substantial increases in new mine production associated with gold discoveries during the 1980s began to make an impression on investors.

From the mid-1980s, many gold producers began to take advantage of new financing and market techniques in the form of gold loans and forward selling. The idea behind gold loans is that gold is borrowed from a financial institution by a company developing or producing from a gold mine. The gold is then sold in the open market to raise capital and the loan is repaid, with interest, from future gold production. Forward selling is a contract to provide gold in the future at a fixed price. This is essentially a producer hedge against declining prices, but also acts to put a ceiling on upward price movements. While both of the market procedures described above tend to exert downward pressure on the gold price, their major effect is to limit the range over which the gold price will fluctuate. They also tend to encourage the development and operation of marginal mines.

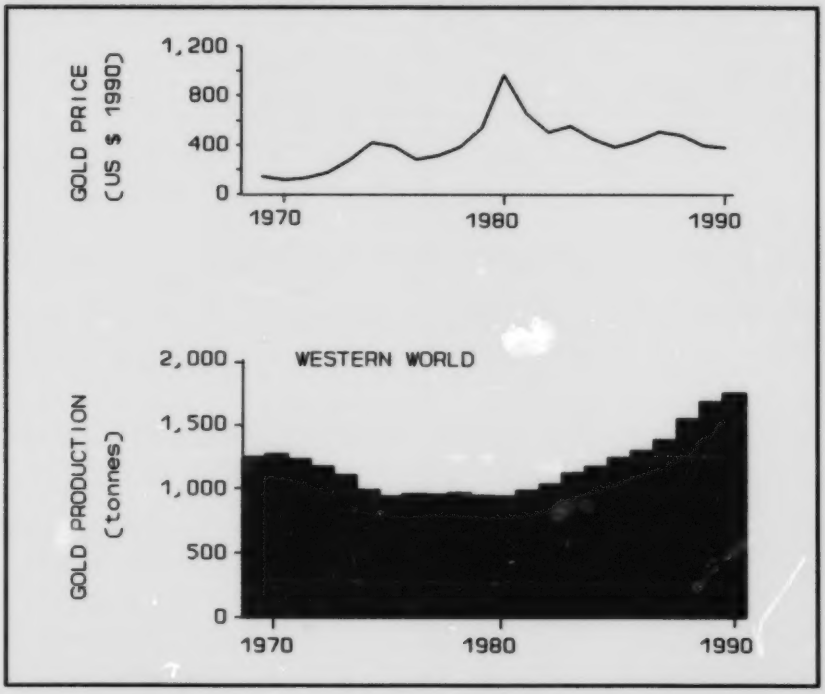
Mine Production

Western World

The relationship between the international gold price and mine production in the Western World during the 1969-90 period is illustrated in Figure 9.[12]

[12] The source statistics are presented in Table 9, Appendix I.

Figure 9. Gold price and mine production in the Western World



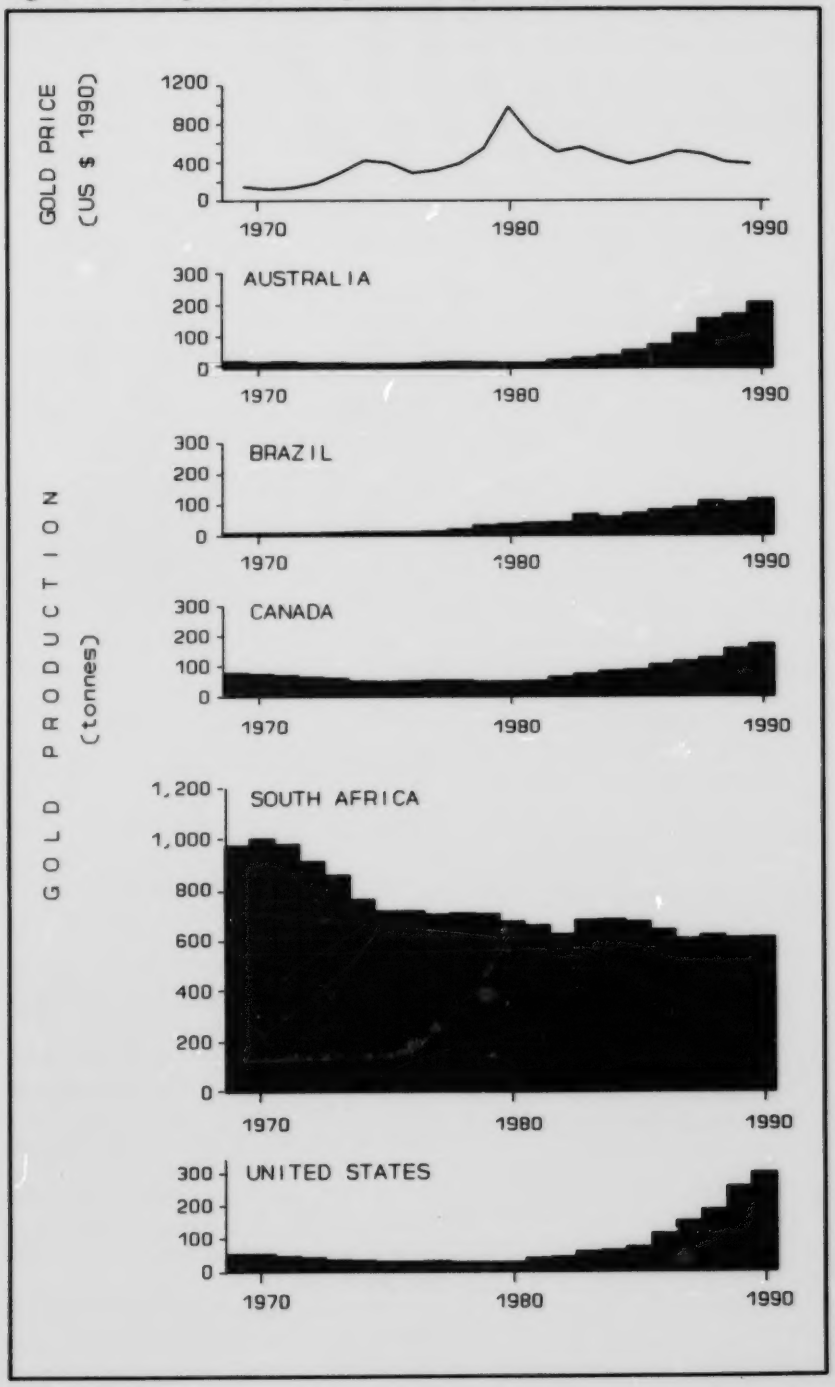
Production increased from 1,252 tonnes in 1969 to 1,734 tonnes in 1990, equivalent to an average annual growth rate of only 2 percent. As shown in Figure 9, this overall trend has two distinct phases:

- 1969-80 when mine production declined on average by 2 percent per year;
- 1980-90 characterized by an annual average growth rate of 6 percent.

Even with the unprecedented rise in free-market gold prices during the 1970s, gold mine production in the Western World during 1975-80 was the lowest since the second world war. This is explained, in part, by the negative relationship which exists in the short term between the gold price and mine production. Within existing mine capacity, an increase in the price of gold results in lowering the cut-off grade and, consequently, reduces the average grade mined and the amount of gold recovered. Figure 9 shows quite clearly that a time lag of approximately 10 years exists between increasing gold prices in the 1970s and rising levels of production in the 1980s. Thus, a considerable period is required for the rehabilitation, expansion, development, and discovery of gold mines to offset depletion and the negative cut-off grade effect, and to lift production.

The worldwide trend in gold production, in part controlled by overall market forces, is made up of distinctive country-specific patterns. Figure 10 takes a more specific look at production within the major gold mining nations. The associated cumulative production statistics and growth rates are sum-

Figure 10. Gold price and mine production by country



marized in Table 3.[13] Table 4 shows the changing market shares of Western World production which have resulted.

[13] See Table 9, Appendix I for the underlying statistics.

Table 3. Growth in gold mine production

	Cumulative Production 1969-90(t)	Annual Growth Rate (%)		
		1969-80	1980-90	1969-90
Australia	1,181	-2	28	12
Brazil	894	13	13	11
Canada	1,769	-4	12	4
South Africa	16,123	-3	-2	-2
United States	1,792	-5	25	8
Other countries	4,248	2	10	5
Western World	26,007	-2	6	1

Table 4. Market share of gold mine production

	Share of Western World Production (%)			
	1969-90	1969	1980	1990
Australia	5	2	2	14
Brazil	3	1	4	4
Canada	7	6	5	10
South Africa	62	78	71	35
United States	7	4	3	20
Other countries	16	9	15	17
Western World	100	100	100	100

Australia

Gold mining in Australia declined after the second world war as the combination of rising costs and the fixed nominal gold price forced mine closures. By the mid-1970s, only four significant Australian gold mines had survived. The recent gold mining boom in Australia, as elsewhere, was triggered by the high gold price of 1980 which led to notable discoveries and developments such as Telfer, Kidston, Boddington, Junction and Granny Smith. By the late 1980s, the eastern goldfields region of Western Australia was the site of hundreds of gold mines, mills, and development projects. The phenomenal acceleration of production during the 1980s, shown in Table 3 to average 28 percent per year, was the highest among the major gold mining countries. Consequently, Australia's gold market share increased from 2 percent in 1980 to 14 percent in 1990. However, most Australian production comes from small, superficial deposits with short lives. Depletion of ore reserves, the taxation of gold mines from 1991, soft international prices, and the reorientation of exploration towards the discovery of more challenging hidden targets, suggest that the recent record production levels will not be sustained. Bullion output could halve over the next decade because of the lack of large, long-life new discoveries.

Brazil

Of the major producers, Brazil experienced the second highest growth rate during the 1969-90 period, averaging 11 percent per year. As a result, Brazil's share of the Western World bullion market rose from 1 to 4 percent (Table 4). Most of the increase is attributable to the work of garimpeiros active in the Amazon Basin. Generally, a much quicker reaction to the positive bullion market signals was possible in Brazil because of the labour-intensive, superficial nature of much of the production, mainly based on alluvial deposits. For example, the discovery of the huge Serra Pelada deposit in the 1970s led to immediate development and production. As a result, Brazil achieved strong growth in the 1969-80 interval, while the other major producers experienced declines in mine output.

The share of Brazilian output accounted for by the garimpeiros tripled from 30 percent of national output in 1969 to nearly 90 percent of the total in 1986. Since then, garimpeiro production has gradually decreased, while Brazilian and international mining companies increased production from such major deposits as Crixás, Fazenda Brasileiro, Jacobina, São Bento, and Morro do Ouro. As a result, company output by 1990 accounted for approximately one-third of Brazilian gold production.

Notwithstanding Brazil's prominent position as a gold producer since the early eighteenth century, almost half (46 percent) of the country's bullion has been recovered since 1969. As shown in Figure 9, output climbed from 9 tonnes in 1969 to a peak of 102 tonnes in 1988, before falling off to approximately 78 tonnes in 1990. A close correspondence can be observed between the gold price and Brazilian gold production (Figure 10), characterized by a time lag of several years.

Canada

Gold production in Canada received a boost from the 1934 gold price increase resulting in a record production of 166 tonnes in 1941. During the post-World War II era of fixed price, gold production showed a steady decline in spite of the federal government's Emergency Gold Mining Assistance program.[14] From the beginning of open-market prices in 1969 until the price spike in 1980, Canadian gold production continued to decline, falling from 79 tonnes to 51 tonnes. Production increased each year throughout the 1980s and reached a new production record of 165 tonnes in 1990. As indicated in Table 4, overall growth during the 1980-90 interval was substantial, averaging 12 percent per year, and doubling Canada's market share from 5 to 10 percent. This was accomplished through the expansion of capacity at existing mines and the opening of more than 60 new mines during the 1980s.

[14] Under the terms of *The Emergency Gold Mining Assistance Act*, operating costs at Canadian gold mines were subsidized in order to prolong mine lives and provide for more orderly closure in the dependent gold mining districts. Gold mines receiving this cost assistance were required to sell their bullion to the Royal Canadian Mint at the official monetary price. Payments between 1948 and 1971 totalled more than $1.2 billion in 1990 US dollars.

South Africa

The Witwatersrand basin of South Africa has made a unique contribution to world gold supply, producing approximately 40 percent of all bullion mined in the world to date. Discovery and development of the Orange Free State and Evander (or Far East Rand) goldfields from the late 1940s to the early 1960s

brought South African output to an all-time high of 1,000 tonnes in 1970. Despite high levels of investment, particularly in mine development, South African production declined by 2 percent per year on average during the 1969-90 period. Figure 9 indicates that the overall drop in annual capacity represents almost 370 tonnes of bullion, from 973 tonnes in 1969 to 605 tonnes in 1990. Coupled with the growth which has taken place elsewhere, South Africa's share of the Western World market, as shown in Table 4, has dropped quite systematically from 78 percent in 1969 to 35 percent in 1990. Deliberate rationalization of uneconomic production, begun by Gencor in 1990, was underway throughout the industry in 1991. Even so, at mid-1991, 10 operating mines collectively producing 80 tonnes of gold per year were not covering their working costs. As a result, South African capacity could fall below 500 tonnes annually by the end of the 1990s.

United States

In the United States, gold production reacted to the 1934 gold price increase and reached a record 157 tonnes in 1940. During the post-World War II era, gold production decreased steadily while the only notable gold mine operating was Homestake. At the beginning of the free-market price era in 1969, the United States produced only 54 tonnes of gold. Output levels decreased steadily to reach a low of 30 tonnes in 1980. The high gold price in 1980 coupled with the application of heap leach technology led to a great resurgence of gold mining in the United States during the 1980-90 interval. Gold output rose at an average annual rate of 25 percent during the 1980s, exceeded only by Australia. Consequently, the United States' market share expanded from 3 to 20 percent. By 1990, output was derived mainly from several hundred lode mines, nearly all in the western states, and a dozen or so placer mines in Alaska. However, the pace of development is falling and environmental concerns appear to be intensifying.[15]

[15] A 1991 survey by the Metals Economics Group shows a decline of more than 40 percent in the number of primary gold projects presently undergoing late-stage development in the United States.

Summary

We have witnessed a substantial worldwide expansion in gold mine production during the 1980s as well as fundamental changes in its geopolitical make-up. In looking ahead through the 1990s, there are two key questions:

- How long can these exponential growth rates be sustained?
- At what point will the respective market shares of South Africa and the other major producers reach a new equilibrium?

Answers are to be found, in part, in the dynamic relationships which exist between the discovery and depletion of gold within each country. This issue is analyzed in Chapter 4.

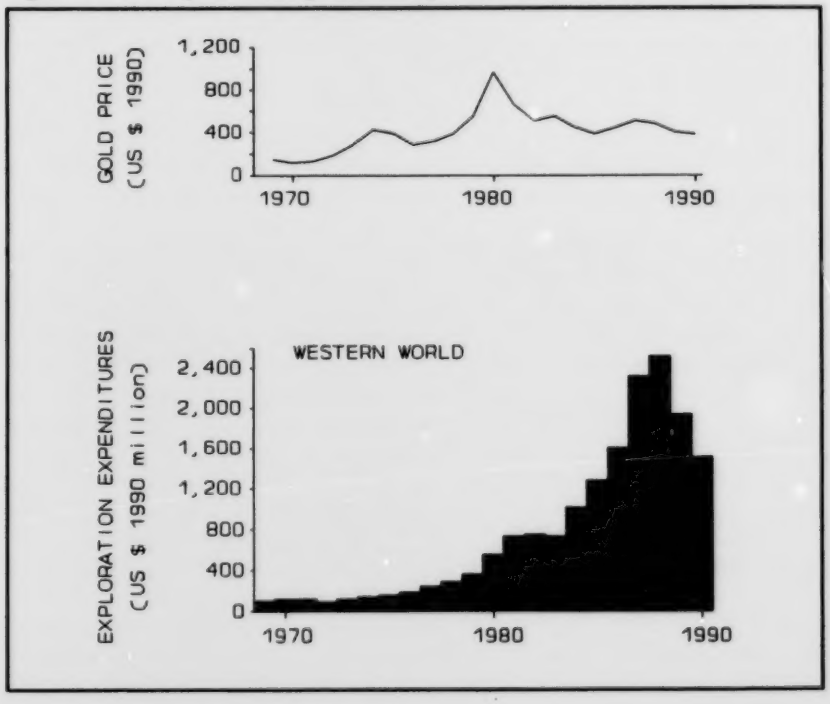
Exploration Expenditures

In the long term, exploration is the connecting link between price, on the one hand, and production on the other. Gold exploration expenditures provide a direct measure of the level of activity in finding and delineating economic gold deposits.

The relationship between the price of bullion, and gold exploration expenditures in the Western World during the 1969-90 period, expressed in constant 1990 US dollars, is presented in Figure 11.[16]

[16] The source statistics can be found in Table 10, Appendix I.

Figure 11. Gold price and exploration expenditures in the Western World



Expenditures for the entire period total almost $17 billion, averaging $770 million per year. Exploration activity is shown to have accelerated from the early 1970s to a peak of over $2.4 billion in 1987, before falling back to about $1.5 billion in 1990. Table 5 indicates that the average annual growth rate in exploration expenditures of 14 percent during the 1969-90 period is much higher than the 5 percent annual rise in the price of gold. It is also notable that there is a seven-year time lag between peak prices in 1980 and peak expenditures in 1987.

Table 5. Growth in gold exploration expenditures

Country	Cumulative Expenditure 1969-90 ($ million)	Cumulative Expenditure 1969-90 (%)	Annual Growth Rate (%) 1969-80	1980-90	1969-90
Australia	2,963	18	14	12	13
Brazil	685	4	41	10	25
Canada	4,968	29	12	13	13
South Africa	1,707	10	8	24	16
United States	3,435	20	21	-4	9
Other countries	3,125	19	27	19	23
Western World	16,883	100	17	11	14

The component trends in gold exploration expenditures by country, illustrated in Figure 12 and summarized in Table 5, are highlighted as follows.

Brazil

Of the total exploration expenditure of nearly $17 billion during the 1969-90 period, Brazil accounted for $685 million or only 4 percent. Investment increased from less than $1 million in 1969 to peak at $77 million by 1984. This peak was nearly matched in 1989 when $75 million was spent on gold exploration. There was a sharp drop, however, in 1990, as expenditures decreased to $46 million.

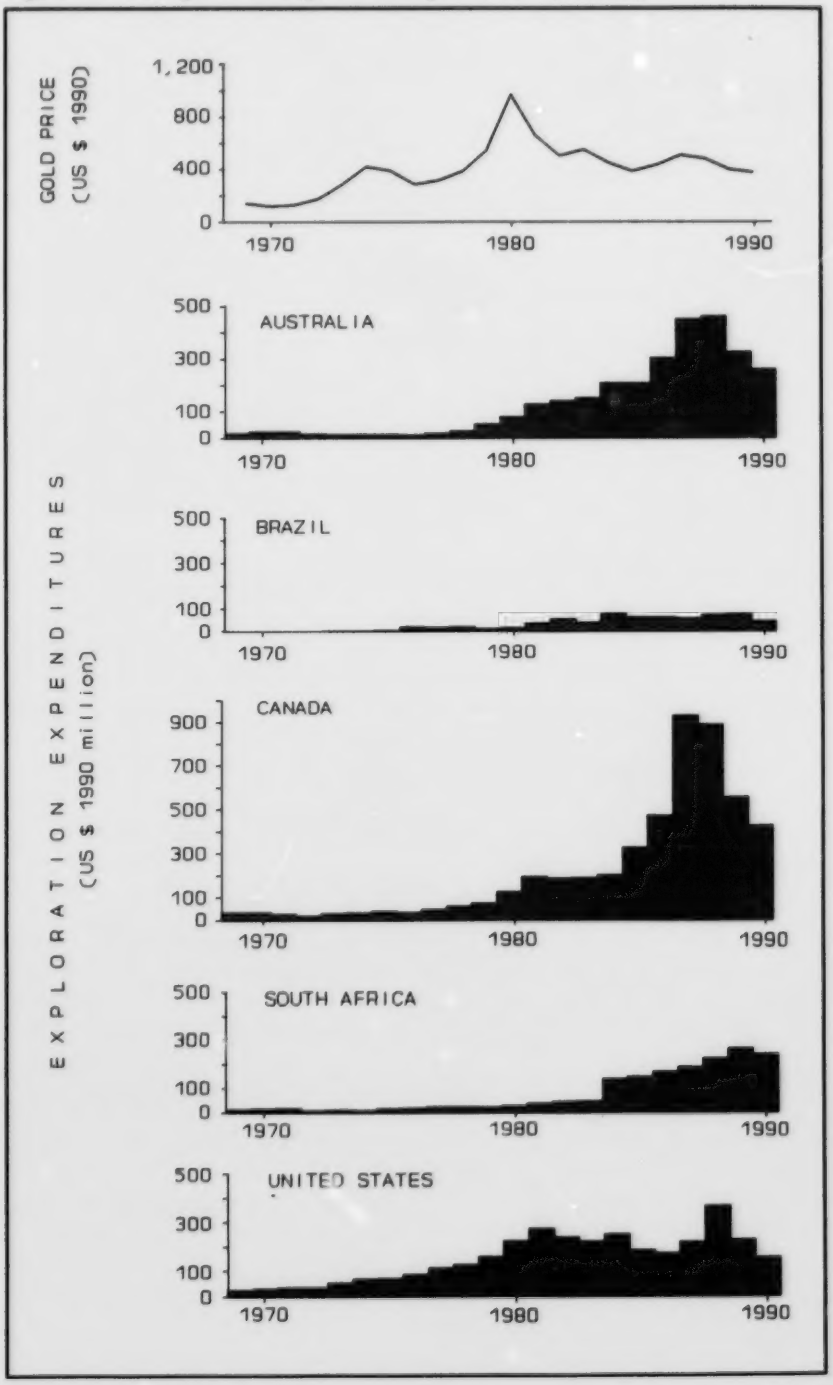
United States

The United States accounted for $3.4 billion of gold exploration expenditures during the 1969-90 period, or 20 percent of the Western World total. Expenditures gradually increased from a low of $28 million in 1969 to reach $278 million by 1981. A levelling-off of investment through the mid-1980s provided the base for a sharp increase in 1988 to a peak of $371 million. This was followed by large decreases as expenditures dropped to only $160 million in 1990.

Australia

Gold exploration expenditures in Australia totalled nearly $3.0 billion during the study period, representing 28 percent of the world total. Investment steadily increased from a low of $13 million in 1976 to peak at $460 million by 1988. Expenditures fell off thereafter and closed the period at $260 million.

Figure 12. Gold price and exploration expenditures by country



South Africa

Only 10 percent, or $1.7 billion, of Western World gold exploration expenditures were accounted for by South Africa during the 1969-90 period. Investment was less than $50 million per year until 1984, but increased during the mid-1980s to peak at $266 million in 1989. The 1990 value showed a slight decline to $242 million.

Canada

Gold exploration expenditures in Canada totalled nearly $5.0 billion during the study period. This represents 29 percent of the total world expenditure. From a low of $20 million in 1972, investment climbed to more than $900 million in 1987. Subsequent years have seen expenditure levels drop, reaching a 5-year low of $429 million in 1990.

Summary

Of the $17-billion exploration expenditure total, Canada accounts for 29 percent, followed by the United States (20 percent), Australia (18 percent), South Africa (10 percent), and Brazil (4 percent), with the remaining 19 percent invested in other countries. However, the 1969-90 growth rates have been highest in Brazil, other countries, and South Africa. The expenditure breakdowns, it should be noted, are quite different than the respective country shares of gold mine production. Future exploration potential is, of course, not necessarily related to past production. The relatively low exploration expenditure total for South Africa is, however, misleading because gold exploration on the Witwatersrand, relieved of most of the high-cost primary work, is mainly concentrated on drilling prospective ground for gold reef extensions. It is interesting to see that exploration expenditures in Canada and Australia rose to the highest levels in 1986-87 and, since then, have been cut back the most. Exploration activity in both countries has been stimulated by strong government incentives which turned out to be temporary – flow-through-share tax write-offs in Canada, and tax-exempt status for gold mine income in Australia.

Summing Up

The economic environment for gold exploration is shaped by three inter-related market variables. Each of these in turn has reached an unprecedented peak in the Western World during the past decade, as follows:

- international price of $971 per ounce in 1980;
- exploration expenditures of $2.4 billion in 1987;
- mine production of 1,734 tonnes in 1990.

Does this mean we are headed for a period of oversupply or, alternatively, is the all-time record wave of production now about to break? Consequently, what are the economic prospects for gold exploration during the 1990s?

4. Outlook for Exploration During the 1990s

Based on these historical price, production, and exploration expenditure footprints, we now examine the outlook for gold exploration during the 1990s.

Time Lags in the Supply Process

The foregoing examination demonstrates that the gold supply process is characterized by appreciable time lags:

- between changes in the price of gold and gold exploration expenditures;
- between changes in gold exploration expenditures and gold mine production.

Corporate exploration strategies do not immediately respond to changes in market price. Concerns that higher prices might be temporary have to be overcome by a perception of permanence. Thus, as shown in Figures 11 and 12, the rise in free-market bullion prices from the early 1970s did not trigger significantly higher exploration expenditures until the end of the decade. On the other hand, gold exploration increased dramatically until 1987-88, while prices were falling from their 1980 peak, and only began to respond to the depressed market signals in 1989-90.

Consequently, worldwide increases in gold mine production associated with price rises from the early 1970s only have been appreciable since the mid-1980s (Figures 9 and 10), reaching a record level in 1990, ten years after the peak price. Given these long time lags and the record levels of gold exploration activity in the 1980s, there is concern that we might be heading for oversupply in the 1990s.

Discovery and Depletion

Here we examine the future consequences of the discovery of large quantities of gold brought on by the record levels of worldwide gold exploration expenditures in the 1980s. Is there a limit to how much new gold can be found before we reach a state of oversupply? By "oversupply" we mean a rate of production that would reduce the price of gold to the "level of discomfort" for currently operating mines or, in other words, to the $250-$300 per ounce range.[17]

Production from nonrenewable resources such as gold deposits represents depletion. Therefore, a certain level of exploration expenditure is required annually for producing gold mines, companies, and countries just to maintain currently installed capacity.

[17] This definition of oversupply was used at a policy workshop on the outlook for gold convened by the Centre for Resource Studies in October 1986. See Mackenzie and Gesing (1987).

The possibility of an oversupply of gold in the 1990s resulting from the discovery and development of economic deposits in the 1970s and 1980s can be examined by linking past levels of exploration expenditure and mine production. We would like to know how much gold has been discovered relative to the gold being depleted in the course of production.

In order to make this connection in a general way, estimates are required of typical exploration costs per ounce of gold recoverable from economic deposits. Assuming a gold price of $400 per ounce, empirical evidence suggests that unit exploration expenditures, disregarding time value considerations, are of the following order:

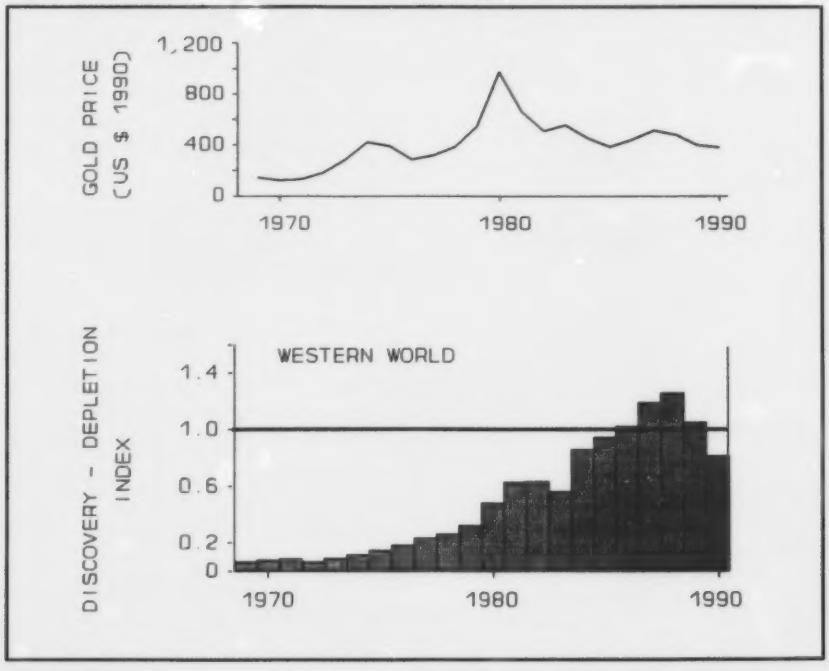
- $35 per ounce in Australia;
- $20 per ounce in Brazil;
- $65 per ounce in Canada;
- $15 per ounce in South Africa;
- $35 per ounce in the United States;
- $45 per ounce in other countries.[18]

[18] The estimates for Australia, Brazil, and Canada have been derived from comprehensive databases which document the gold exploration, discovery, and development record from 1969. Estimates for South Africa, the United States, and other countries, are more speculative.

Applying these unit discovery costs to the mine production and exploration expenditure statistics illustrated in Figures 10 and 12, annual and cumulative estimates have been made of ounces of gold discovered as a proportion of gold mine depletion. An index of 1.0 means that the amount of gold discovered would be just sufficient to balance the amount being depleted.

Overall results for the Western World during the 1969-90 free-market era are presented in Figure 13.

Figure 13. Index of gold discovered to gold depleted in the Western World



In summary,

- only during 1986-89 were exploration expenditures at a high enough level to discover more gold than was being depleted. However, in 1990 the discovery-depletion index once again dropped below 1.0 (to 0.83);

- for the overall 1969-90 period, the discovery of gold is estimated to have been sufficient to replace only 59 percent of the gold depleted from ore reserves at operating mines.

Thus, on a worldwide basis, there is little evidence to support the premise that there will be an oversupply of gold in the 1990s resulting from successful exploration in the 1970s and 1980s.

Discovery-depletion indexes by country are illustrated in Figure 14. The major producers show distinctive discovery-depletion patterns.

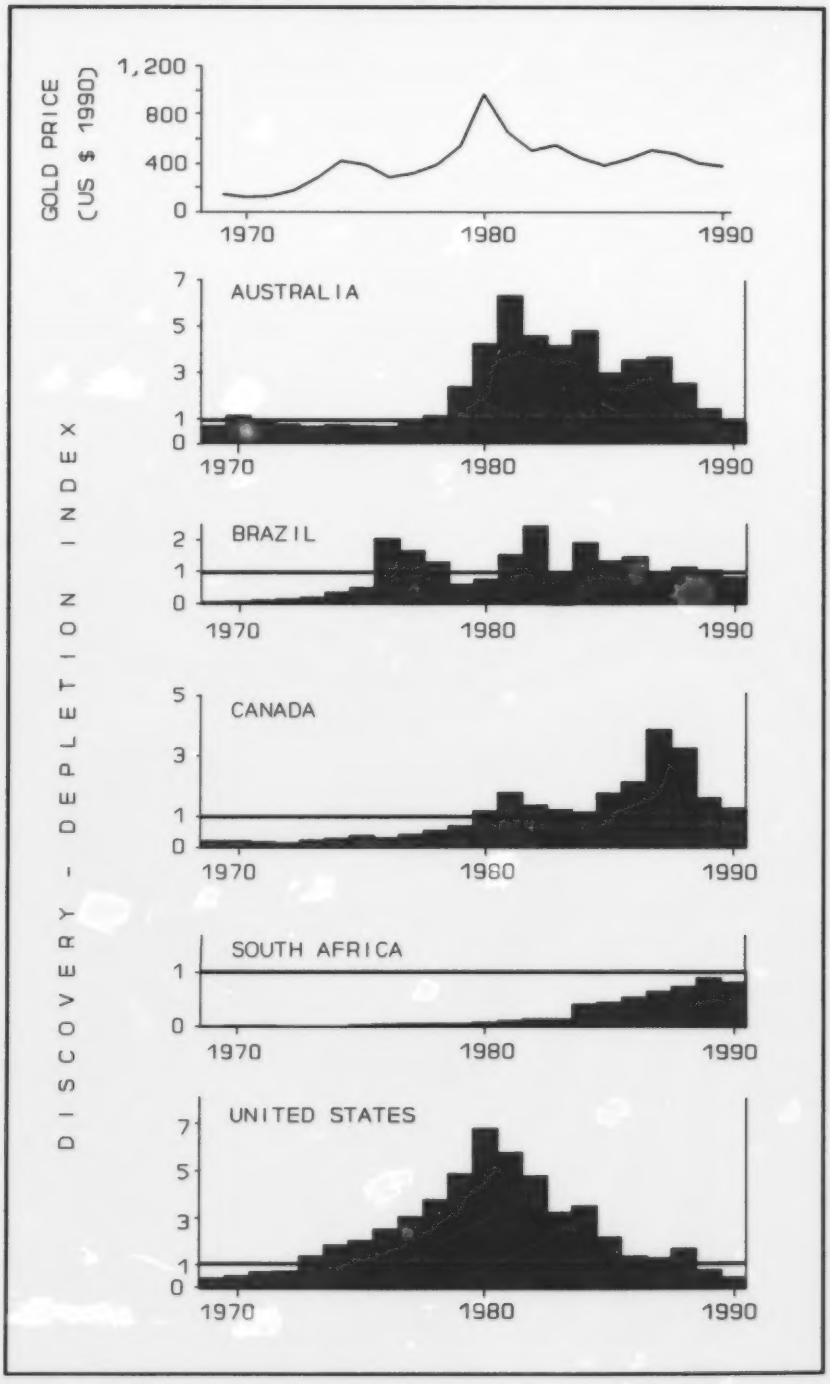
Gold discovered in Australia and the United States has exceeded mine production by wide margins of 2.2 times and 1.9 times, respectively, during the 1969-90 period. A zenith of almost seven-times production was reached in 1980 in the United States and in 1981 in Australia. These findings explain the relatively high growth rates in mine production – 25 percent and 28 percent per year, respectively – achieved by these countries during the 1980-90 interval. However, by 1990, discovery and depletion were just in balance in Australia, and exploration replenishment had fallen to approximately 50 percent of production in the United States, indicating that the period of growth is coming to an end.

The Canadian pattern is shown to be somewhat more subdued, lagging behind the discovery-depletion paths which characterize Australia and the United States. Gold discovered in Canada over the 1969-90 period was 1.3-times greater than gold produced, attaining a peak of more than three-times output in 1986-87. Discovery and depletion were back in equilibrium by 1990.

The discovery-depletion index for Brazil, approximately in balance over the 1969-90 period, is misleading. Most of Brazil's production has been from garimpeiros working alluvial deposits, requiring little in the way of systematic exploration. Virtually all of the exploration has been carried out by international and Brazilian mining companies. By the late 1980s, mining company discoveries were providing the basis for substantial growth in gold production while garimpeiro production was beginning to fall quite sharply.

In South Africa, the discovery of gold in the overall 1969-90 period is estimated to be sufficient to replace only about 20 percent of the gold depleted from ore reserves at operating mines. With a notable increase in gold exploration expenditures from the mid-1980s and the continuing decline in mine production, discovery and depletion were moving towards equilibrium by 1989-90.

Figure 14. Index of gold discovered to gold depleted by country



Summary

The country-specific results presented help explain the momentous shift in market shares which has occurred since 1969 (Table 2) away from South Africa to the other major producers and newly emerging players.

In worldwide terms, the discovery-depletion findings lead us to conclude that there is little evidence to support the premise of an oversupply of gold in the 1990s resulting from successful exploration during the 1970s and 1980s.

Dynamic Growth Factors

Given the foregoing discovery-depletion results, what explains the growth in gold mine production during the 1980s? What does this mean in terms of the future potential for gold exploration? There are four main factors to consider.

First, the growth in gold mine production which has taken place may be attributed as much to the effect of higher prices and new technology on cut-off grade as to the discovery and delineation of previously unknown reserves. While there is a negative relationship between price and production in the short term within existing capacity, there are opportunities to expand capacity in the medium term from known but previously uneconomic reserves.

Second, much of the record investment which took place during the 1980s was in the nature of revitalization for an industry that, in most parts of the world, had been suffering a steady decline throughout the 1950s, 1960s, and 1970s. Despite the recent prosperity of gold mining, the longer-term downward trend was not easily or quickly reversed.

Third, increases in mine production arising from small, open pit deposits with short lives will be difficult to maintain very far beyond 1990. For example, more than half of Australia's gold production comes from mines with reserves of less than three years.

Fourth, the annual worldwide level of gold exploration expenditures of approximately $2 billion during the late 1980s, cannot be sustained. In addition, the inevitable transition in exploration focus from re-exploration of past producers and known occurrences to grassroot targets surely will increase finding costs.

In the long run, our findings indicate that it will be a challenge to discover and delineate the ore reserves required just to sustain present rates of gold mine production. In this respect, the potential for gold exploration is excellent.

Future Price Possibilities

As we have seen, gold exploration expenditures crested in 1987-88. The peak year for mine production in all likelihood will prove to be 1990. Gold mining will no doubt fall back to somewhat lower sustainable levels during the 1990s. There is unlikely to be an oversupply of bullion in the foreseeable future.

These worldwide trends should be welcome news for countries and companies committed to gold exploration. The interrelated question of what future price of gold can be anticipated remains. All attempts to forecast the gold

price are based in some way on historical experience. Some approaches simply extrapolate the price itself into the future; other methods establish relationships between the price and appropriate explanatory variables.[19] These historical connections may be modified by opinions on possible future developments in the gold market which are not reflected in past experience.

When examining the economics of gold exploration, the appropriate timeframe for price projection lies far out in the future. Under normal circumstances, it takes 4 to 8 years to find and delineate an economic gold deposit. Then, another 1 to 3 years typically would be required to develop the deposit to production. The relevant gold prices for exploration planning, then, are the ones which will prevail when the economic deposits not yet discovered have been developed to the point of producing gold for sale, towards the turn of the century and beyond. How ever do we project prices this far out into the uncertain future?

According to Jastram (1977), long-term historical evidence indicates that the real price of gold has displayed a flat trend over four hundred years. Despite prolonged deviations in the underlying conditions of gold supply and demand across decades and centuries, the price tends to return sooner or later to this long-term average. His "golden constant" price in 1990 terms lies between $270 and $350 per ounce.

The 1970s witnessed an extraordinary increase in investor demand for gold. Because this demand probably has been augmented permanently, and because the high level of mine production achieved by 1990 is unlikely to be sustained, it is hard to imagine the gold price dropping below Jastram's long-term mean.

According to Anders (1987), only one long-term gold forecast has remained valid over time, and that is the one made by Einzig (1972). Einzig concluded that the price would settle into a range around $140 per ounce in 1970-71 terms, equivalent to $440 per ounce in 1990 dollars.

Stein's paradox in statistics concerns the use of observed averages to estimate unobservable quantities.[20] Simply stated, Stein shows that the best guess about the future usually is obtained by computing the average of past events. Therefore, in speculating on the future price of gold, we should keep in mind that, as shown in Figure 1, the price of gold has averaged $409 per ounce during the post-1969 era of free-market conditions.

Can the future gold price be projected in a meaningful way for exploration planning? For economic appraisal purposes, all we can do is

- strive to remove the temporary influences of current market events from our thinking about future prices;
- base our assessments on a wide range of future price possibilities with the hope that we have bounded the actual future average price;
- carry out our evaluations as much as possible on the basis of relative cost league comparisons, independent of future gold price predictions.

Based on the foregoing considerations, for present-day (1992) assessment of the long-term economic potential of gold exploration, perhaps we could address the elusive price variable as follows:

[19] The pricing models developed by the International Gold Corporation (1985), and Kaufmann and Winters (1989) are of this type. For example, the IGC regression equation considers gold price to be a function of five independent variables: the dollar exchange rate, world liquidity, real interest rates, unanticipated inflation, and an index of political tension. Such models no doubt help us to understand past price changes. However, considering their potential to predict the future, it is doubtful that the independent variables are any easier to forecast than the price of gold itself.

[20] See Efron and Morris (1977).

- use an expected gold price of $400 per ounce for an initial "base case" evaluation;
- examine the sensitivity of economic results to a range of possible future prices, varying from $300 to $500 per ounce;[21]
- determine the breakeven price of gold required to yield a minimum acceptable return on investment;
- consider the $300 and $500 per ounce gold prices as 95-percent lower- and upper-limit values, and describe a probability distribution through the three price points for the purpose of carrying out a probabilistic risk analysis of possible future outcomes.

[21] As suggested in Chapter 3, gold loans and forward selling should act to restrict the range of possible future prices during the 1990s so that we are unlikely to see the 1980s high/low price differential of nearly $600 per ounce.

Summing Up

Record levels of worldwide gold exploration during the 1980s are unlikely to result in an oversupply of gold during the 1990s. In fact, our findings indicate that it will be a challenge to discover and delineate the ore reserves required just to sustain present rates of production. The all-time Western World record output of 1,734 tonnes of bullion set in 1990 will likely stand for many years to come. Thus, the long-term future price of gold can be expected to be maintained at its historical average of above $400 per ounce.

Generally, the present-day economic environment for gold exploration is positive.

5. Potential of Exploration for Wealth Creation

While the overall market forces examined in Chapter 4 provide encouragement for gold exploration, they are not sufficient in themselves to justify investment. For this purpose, a more specific assessment of the economics of exploring for gold is required. We need to know to what extent the search for gold deposits represents an economic investment and more intrinsically, a wealth-creating endeavour.

The gold supply process advances from exploration through development to production. Investment starts with the search for economic gold deposits. Thus, exploration occupies a strategic up-front position in the supply process.

Gold exploration cannot be justified as an end in itself. Its economic viability is determined by the costs, risks, and returns associated with the three-phase supply process.

In this final chapter, we examine the economic potential of gold exploration for wealth creation in Australia, Brazil, and Canada based on the historical record.

Methodology

Potential Value of Exploration

The potential of gold exploration for wealth creation is defined here as the difference between the revenues realized from gold production and all the associated costs, including an allowance for the cost of capital. Potential value represents the increase in real wealth which results from investing in gold exploration from the viewpoint of society as a whole, and indicates what is available for sharing between companies and governments prior to taxation and other public policy considerations.

Evaluation Criteria

The potential value of gold exploration can be conveniently portrayed by the time distribution of average cash flows associated with the discovery of an economic gold deposit. The long-term attractiveness of exploration is evaluated from the start of the search process. The medium-term view from the start of development measures the return from successful exploration exclusive of the exploration-phase estimates.

Exploration Economics

The following two indicators, derived from the average cash flow distribution, are used in this chapter to illustrate the potential value of gold exploration.

Expected Value per Economic Discovery

An exploration expenditure E is required on average for the discovery and delineation of an economic deposit, yielding an average return R. Thus:

$$EV = R - E$$

where

EV	=	expected value per economic discovery;
R	=	average return from development and production associated with the discovery of an economic deposit;
E	=	average exploration cost required to find and delineate an economic deposit.

To make a valid comparison, R and E are expressed as time-adjusted values at the start of exploration, using a cost-of-capital estimate for the investment as the discount rate.

Expected Rate of Return

The expected rate of return on investment also can be derived from the time distribution of average cash flows for an economic deposit. By definition, rate of return is the discount rate that equates the present value of the positive cash flows with the present value of the funds invested. In economic terms, rate of return represents the average percentage annual return which gold exploration is expected to yield over the three-phase supply cycle.

Development Economics

The development of an economic deposit is the result of successful exploration. Because exploration time and cost have been expended in resolving risks to arrive at this favourable outcome, the economic potential of mine development, as we will see, is generally much more attractive than the economics of exploration. The following two criteria are applied here to portray the development potential of economic gold discoveries.

Expected Net Present Value

The expected net present value converts the anticipated time distribution of cash flows for development and production into an equivalent dollar value at the start of development. To do this, each cash flow is discounted back to this point using the cost-of-capital rate. The present value components are then summed to yield the expected net present value.[22]

[22] With reference to the exploration criteria outlined above, the expected net present value is directly related to R, the only difference being that R is time-adjusted to the start of exploration rather than to the start of mine development.

Expected Rate of Return

The expected rate of return for mine development is the discount rate which equates the present value of the positive cash flows from production with the present value of the development-phase investment. In other words, the expected rate of return is the discount rate which yields a zero net present value.

Evaluation Procedure

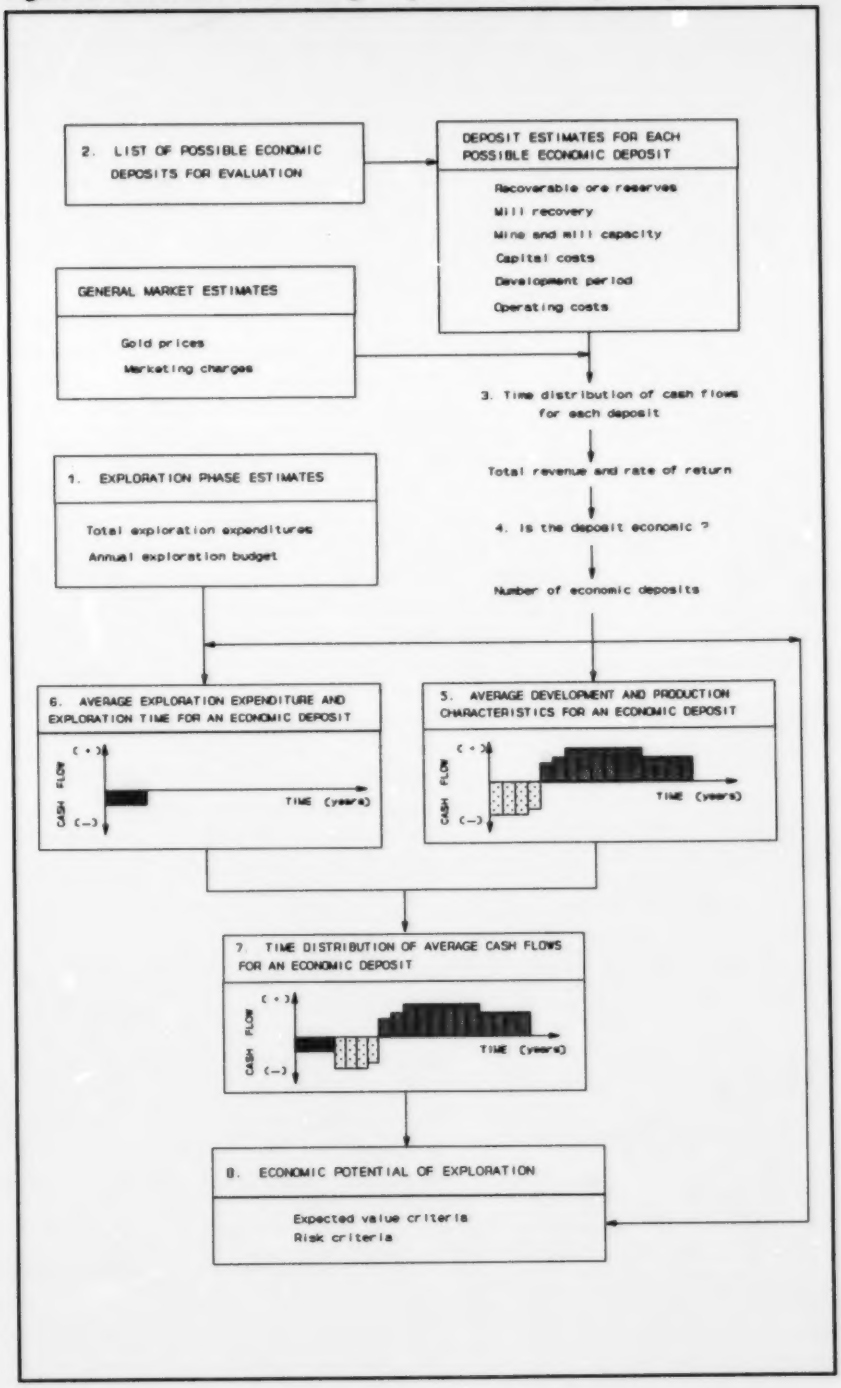
In the evaluation procedure described here, gold exploration economics is appraised on the basis of historical experience, placed in the context of current economic and technological outlook conditions. This methodology is intended to provide objective and relevant appraisals for strategic planning purposes. The approach adopted is predicated on the past being able to tell us something useful in planning for the future. Two main assumptions are incorporated. First, deposits yet to be found resemble, in economic terms, those that have been discovered to date. Second, the cost of making a future discovery will be comparable to the cost in the past. However, since the gold supply process is dynamic, we should endeavour to discern time trends within the overall historical experience.

The database for assessing the potential value of an economic gold deposit comprises the documentation of actual experience in exploration, development, and production over a relevant historical timeframe – the post-1969 free-market era is selected in the appraisals which follow for Australia, Brazil, and Canada. For policy and planning purposes, this information is then evaluated in the context of current outlook conditions.

In essence, the methodology (diagrammed in Figure 15) follows these steps.

1. Total gold exploration expenditures are estimated for the historical time period of interest and an annual exploration budget rate is assumed.
2. Possible economic deposits discovered as a result of these expenditures are classified by discovery date and listed for evaluation.
3. The cash flow characteristics of the development and production phases for each of these possible economic discoveries are evaluated on the basis of current outlook market conditions and deposit-specific estimates.
4. Discoveries that, on evaluation, satisfy minimum conditions of size and profitability are designated as economic deposits.

Figure 15. Procedure for assessing the potential value of gold exploration



5. Cash flow characteristics of the development and production phases for all economic gold deposits are first analyzed to depict the economics of mine development and then averaged.
6. Total exploration expenditures, which cannot in general be directly associated with the economic discoveries, are prorated across all economic deposits evaluated.
7. Estimates for the exploration phase are integrated with the average characteristics for the development and production phases to portray the time distribution of average costs and revenues for an economic gold deposit from the start of exploration to the end of production.
8. Several expected value criteria and risk measures earlier described are derived from the assessment. These indicators reflect the economic potential of gold exploration.

More specifically, the development and production phase characteristics for each of the possible economic discoveries (step 2 above) are evaluated (step 3), as shown in Figure 15, by combining the general market estimates with estimates of the following individual deposit parameters: recoverable ore reserves; mill recovery factor; a stripping ratio for open pits; mine and mill capacities; capital costs, including the working capital requirement; the length of the preproduction development period; and operating costs. These estimates, based on the actual historical record, attempt to portray how each gold deposit would look today if it were awaiting development. A number of measures of economic worth are derived from the resulting cash flow distributions, including the total sales revenue generated and the rate of return. Those discoveries that satisfy minimum conditions for total revenue (size) and rate of return (profitability) are deemed to be economic (step 4). The return characteristics of the economic gold deposits are analyzed to portray the economics of mine development. The cash flow estimates for all economic deposits are then averaged (step 5), resulting in a time distribution of average cash flows for the development and production phases of the gold supply process.

With respect to appraisal of the exploration phase (step 6), the total exploration expenditure estimate (step 1) is divided by the number of economic deposits assessed (step 4) to determine the average exploration expenditure required to find and delineate an economic deposit. The assumption of an annual exploration budget rate is used to ascertain the time distribution of this average exploration expenditure. These estimates for the exploration phase are then integrated with the appraisals for the development and production phases.

As portrayed in Figure 15, the end result of this evaluation process is an assessment of the time distribution of average cash flows for an economic deposit over the entire gold supply process (step 7). The expected value and risk measures which are derived from these estimates to portray the before-tax, potential value characteristics of gold exploration and development in Australia, Brazil, and Canada (step 8) have been outlined earlier.

Gold Exploration in Australia, Brazil, and Canada

The illustrative assessments which follow concern exploration for new primary gold deposits in the modern free-market era.[23] Three cases are considered:

[23] Exploration of new projects associated with pre-1969 discoveries as well as alluvial gold exploration are excluded.

- Australia, 1969-86;
- Brazil, 1969-88;
- Canada, 1969-88.[24]

[24] There are two reasons for selecting 1969 as the starting point: open-market gold prices were first established at this time and, consequently, 1969 was chosen as the initial year for the Brazilian database. The end year of each series is determined by the present status of the database utilized.

Money values are once again expressed in constant 1990 United States dollars. The appraisals are made on a potential-value or before-tax basis. A 10-percent cost of capital is applied to time-adjust cash flows.

One aspect of the evaluation is to determine which of the gold deposits discovered since 1969 would be economic under today's conditions. For this purpose, an economic deposit is defined as a discovery which realizes a total revenue of at least $15 million and a rate of return of at least 10 percent.[25]

[25] The $15-million minimum size is designed to keep the data-gathering task manageable while ensuring that any deposit of significance is included in the evaluation.

An international gold price of $400 per ounce is used to assess the potential value of gold exploration. This expected or mean price outlook is bounded by upper- and lower-limit prices for gold and by-product silver as shown in Table 6.

Table 6. Long-term price projections (1990 US dollars)

		Price Variants		
	Price Basis	Lower-Limit	Expected	Upper-Limit
International price:				
Gold	ounce	325	400	500
Silver	ounce	4	6	9
Parallel-market premium for Brazilian producers (percent)		10	25	40

In Brazil, the economic evaluation is complicated by the existence of two main cruzeiro-dollar exchange rates – the lower "official" rate, and the higher "parallel market" rate. Brazilian producers are allowed to sell their gold at the parallel market rate. On the other hand, the exploration expenditure, capital expenditure, and operating cost estimates used in the study have been converted from cruzeiros to US dollars using the official exchange rate. This tends to overvalue these costs. Therefore, in order to be both realistic and consistent, the parallel market rate is used to determine the gold price for Brazilian producers. As shown in Table 6, an expected premium of 25 percent is applied for this purpose.[26]

[26] The parallel-market premium has averaged about 28 percent from 1969, and 40 percent since 1980. Consequently, the 25-percent premium assumed for comparative purposes is not particularly favourable to Brazil.

The Australian, Brazilian, and Canadian data on gold exploration expenditures, and the number of significant deposits discovered which could possibly satisfy our "economic deposit" definition, are summarized in Table 7.[27] Additionally, an annual exploration budget of $5 million, considered to be an organizationally efficient rate of expenditure, is applied in determining the average exploration period required to discover and delineate an economic deposit.

[27] Note that these exploration expenditures are lower than those discussed in Chapter 3 and shown in Table 10, Appendix I, because of the exclusion of re-exploration of old discoveries and alluvial gold exploration. Lists of the possible economic deposits evaluated are provided in Tables 11-13, Appendix II.

Table 7. Summary of database for international comparison

	Australia	Brazil	Canada
Total exploration expenditures ($ million)	526	388	2,899
Number of possible economic deposits for evaluation	61	34	134

Base Case Results

An overview of the case study findings follows. More comprehensive numerical results, including the lower-limit and upper-limit price variants, can be found in Tables 16-18, Appendix III.

Exploration Economics

For the expected prices and other specified evaluation conditions, 41 of the 61 discoveries in Australia, 23 of the 34 discoveries in Brazil, and 43 of the 134 discoveries in Canada are found to be economic. In each case, the cost and revenue characteristics of these economic deposits are combined with the total exploration expenditure and budget rate estimates to assess the time distribution of average cash flows for an economic deposit. The cash flow distributions for gold exploration in the three countries are presented in Figure 16 and summarized in Figure 17. The total cash flow generated by an economic deposit averages $56 million in Australia, $196 million in Brazil, and $102 million in Canada.

Based on the cash flow results portrayed in Figures 16 and 17, assessments are made of the potential value of gold exploration as summarized in Figure 18. The average undiscounted cost of discovering an economic gold deposit in Australia and Brazil ($13 million and $17 million respectively) is found to be only about one-quarter of the average exploration expenditure required in Canada ($67 million). The bottom-line expected values demonstrate that gold exploration in Australia and Brazil is a wealth-creating activity, offering potential to increase substantially the economic surplus available to society. While the expected rates of return are similar – 18 percent in Australia and 19 percent in Brazil – the expected value per economic discovery in Brazil ($28 million) is more than twice that associated with gold exploration in Australia ($12 million), indicating that the Brazilian discoveries have been much larger on average than the economic gold deposits found in Australia.[28]

On the other hand, gold exploration in Canada is found to be a strongly uneconomic proposition overall. The expected value per economic deposit is –$24 million. Also, the 4-percent expected rate of return falls 6 percent short of the breakeven level. This negative performance mainly reflects the exceptionally high average cost associated with the discovery of an economic deposit.

[28] If the parallel-market premium were removed, the expected value of gold exploration in Brazil would drop to $8 million and the expected rate of return would fall to 13 percent.

Figure 16. International comparison of time distributions of average cash flows for an economic deposit

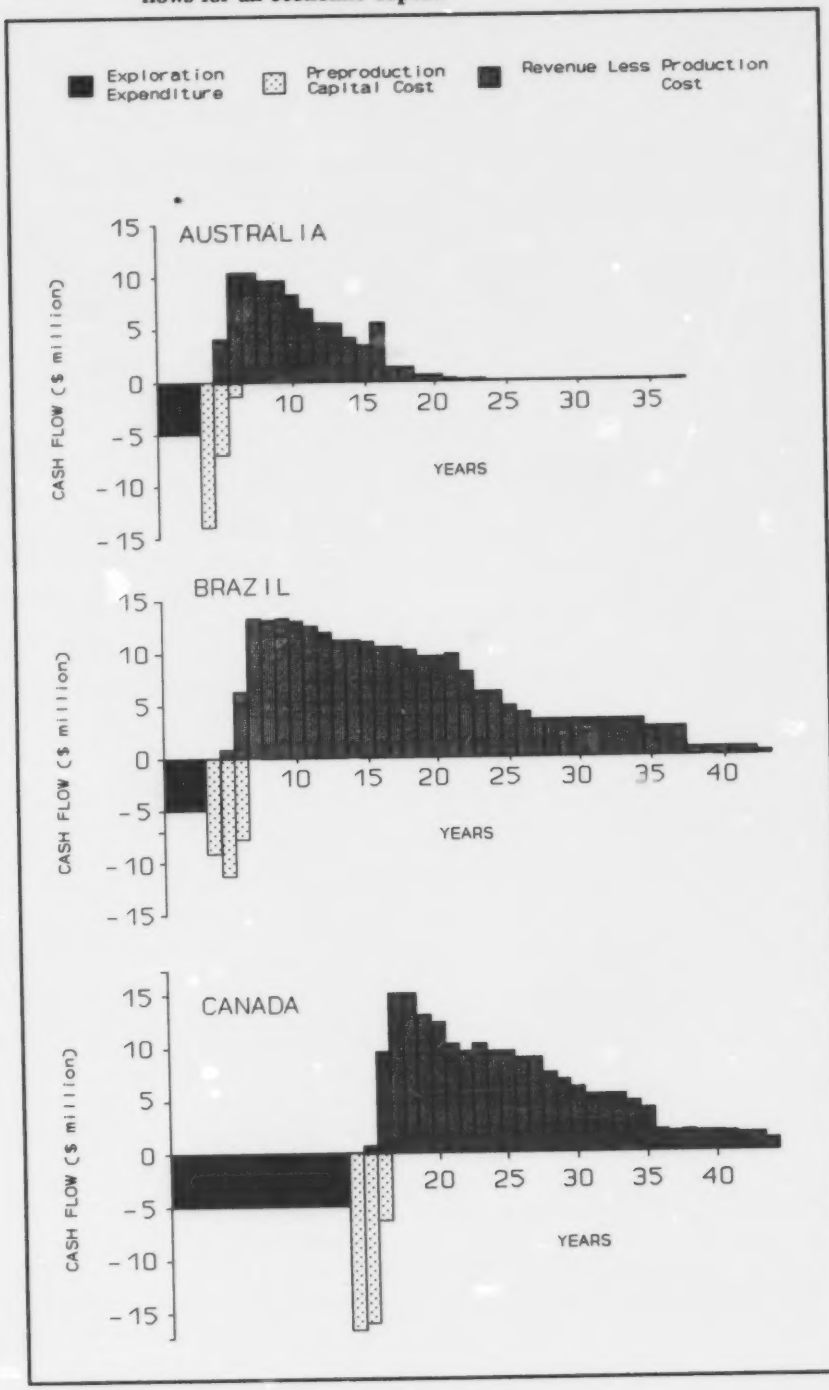


Figure 17. International comparison of average undiscounted cash flow characteristics for an economic gold deposit

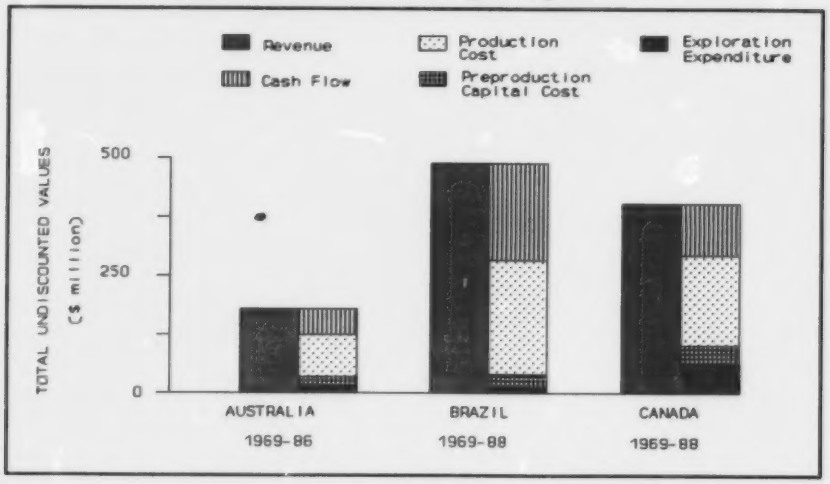
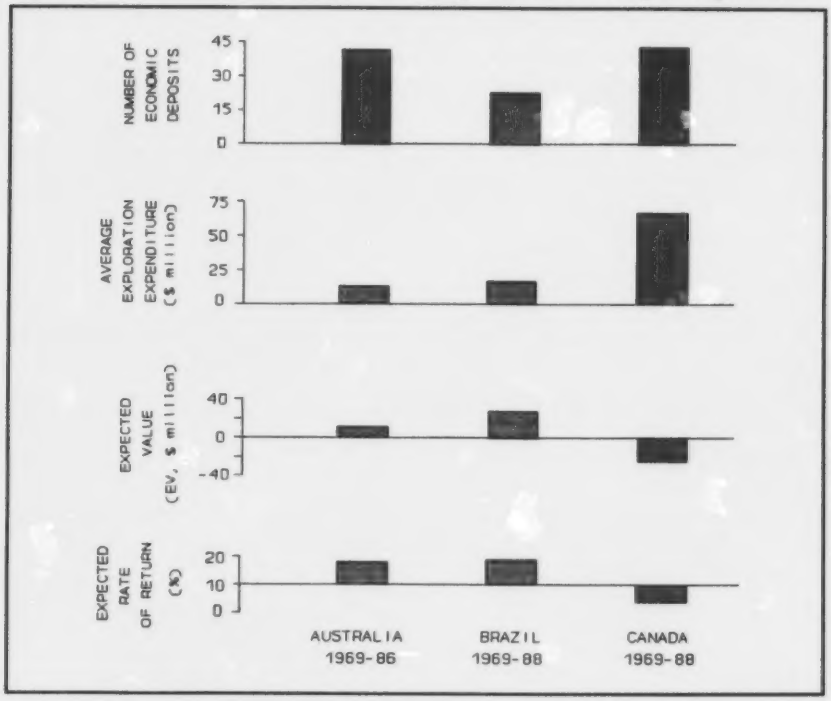


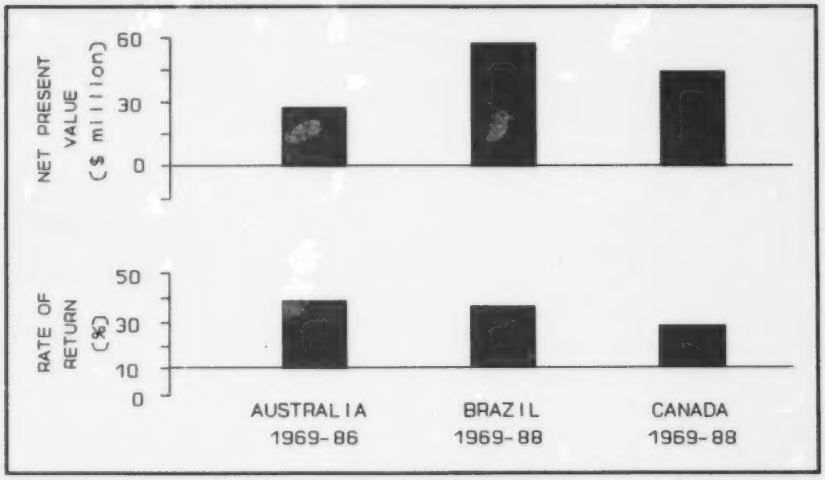
Figure 18. International comparison of expected values for gold exploration



Development Economics

The expected values for gold mine development, derived from the development and production-phase cash flows shown in Figure 16, are illustrated in Figure 19.

Figure 19. International comparison of expected values for gold mine development



Economic gold deposits in all three countries clearly represent worthwhile exploration targets. The economic discoveries in Australia and Brazil are shown to be somewhat more profitable on average than those found in Canada to date. The average net present value per economic discovery is more variable, ranging from $28 million in Australia to $44 million in Canada and $57 million in Brazil. These variations mainly reflect differences in the average size of economic gold deposits found in the three countries during the comparative time periods.[29]

[29] The Hemlo deposit has a notable impact on the average size of Canadian economic discoveries. In Brazil, the Sera Pelada, Crixás, Morro do Ouro and Fazenda Brasileiro discoveries are particularly influential.

Time Trends in Exploration Performance

The base case results mask important changes in the economic performance of gold exploration which have occurred in all three countries since 1969. Time trends in the economic potential of gold exploration in Australia, Brazil and Canada are examined in this section. Performance during the 1969-82 interval is compared in each case with results for the period from 1983, roughly corresponding to the worldwide boom in gold exploration. The individual country databases are broken down in Table 8 by time interval. The low level of exploration in Brazil during the first interval somewhat limits the reliability of the associated economic assessments.

Table 8. Summary of database for international comparison by time interval

		Total Exploration Expenditures ($ 1990 million)	Number of Possible Economic Discoveries for Evaluation
Australia:	1968-82	253	16
	1983-86	273	45
Brazil:	1969-82	98	11
	1983-88	200	23
Canada:	1969-82	773	68
	1983-88	2,216	66

The expected values for gold exploration are compared in Figure 20. Figure 21 illustrates the associated trends as viewed from the start of mine development.[30] In general, there appears to be a falling off in economic performance with time. However, there are several notable differences in the direction and magnitude of the changes which have occurred in the three countries.

[30] A more comprehensive set of time trend results is presented in Table 19, Appendix III.

The trends in Australia can be summarized as follows:

- sharp improvement from $23 million to $9 million in the average undiscounted exploration expenditure per economic discovery;
- strong decline in the average size but significant increase in the average profitability of the economic gold deposits discovered;
- accordingly, while the expected value of gold exploration per economic discovery falls from $18 million to $8 million, the expected rate of return rises from 16 percent to 19 percent.

In the case of Brazil, the main time trend features are

- average discovery cost maintained at $16-17 million;
- precipitous drop from $154 million to $23 million in the expected net present value per economic deposit, reflecting the discovery of the four largest deposits in the earlier 1969-82 interval;
- strong associated decline in the economic performance of gold exploration. The expected value per economic discovery falls from $99 million for 1969-82 to only $3 million during the 1983-88 interval, and the expected rate of return decreases from 28 percent to 12 percent.

Figure 20. **International comparison of time trends in expected values for gold exploration**

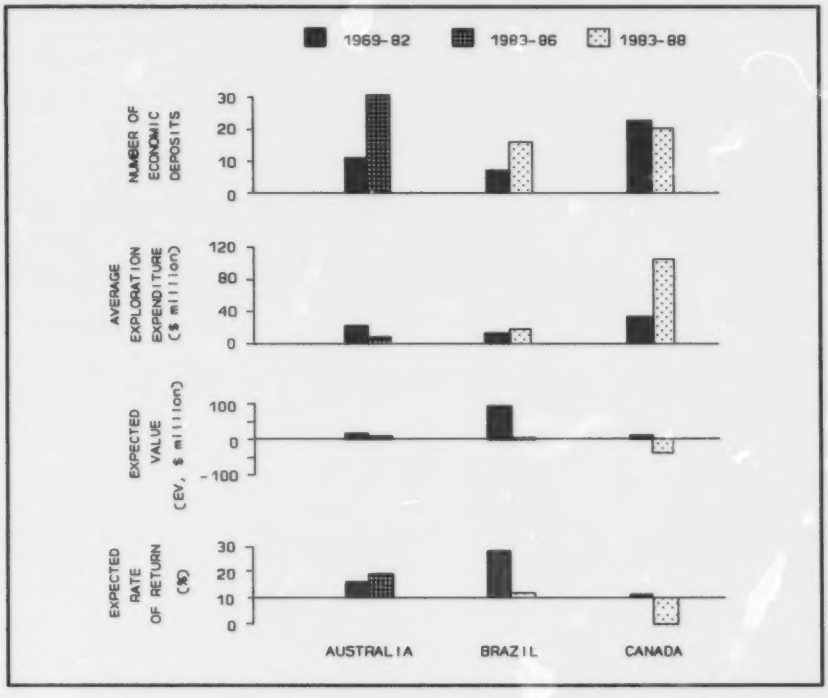
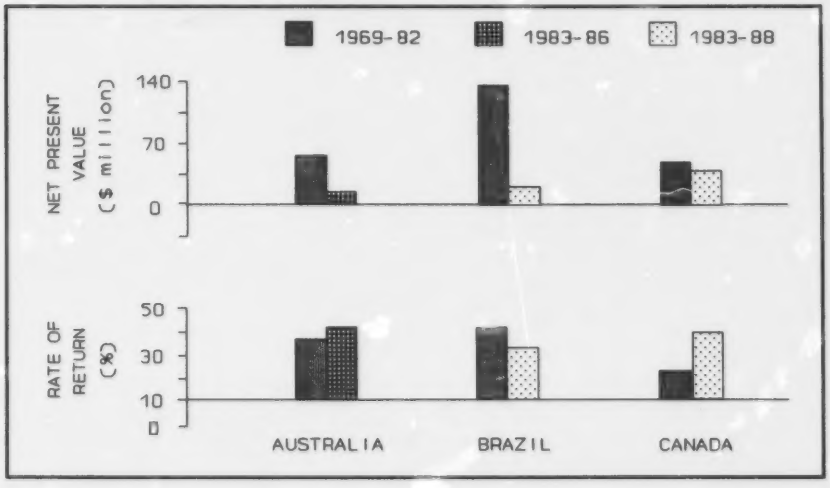


Figure 21. **International comparison of time trends in expected values for gold mine development**



The main changes which have occurred in Canada are

- three-fold increase from $34 million to $106 million in the average undiscounted exploration expenditure per economic discovery;
- the return characteristics of the economic discoveries are found to hold up well with time. While the average net present value per economic discovery decreases somewhat, there is a substantial improvement in the average rate of return;
- the economic potential of gold exploration falls from the breakeven point in 1969-82 to a hopelessly uneconomic situation during the 1983-88 interval. The main cause of this ruinous change is the staggering increase in average discovery costs.

Breakeven Gold Price Requirements

The preceding assessments of the potential value of gold exploration assume an international gold price of $400 per ounce. The relevant timeframe for the $400 projection only begins some 5 to 10 years into the future. Thus, when evaluating the economics of gold exploration, we don't really care what the price of gold will be in 1993, 1994, or even 1996. The relevant gold prices are the ones which will prevail when the unknown economic gold deposits currently being sought are in a position to market gold, most likely from the late 1990s to the turn of the century and beyond.

Even with the best possible market research expertise, it is extremely difficult, if not impossible, to meaningfully predict the price of gold so far into the future. We would be surprised if actual gold prices over the relevant timeframe for exploration planning were to average out anywhere close to the projected $400 per ounce.

Under such conditions of uncertainty, a related question can be usefully addressed: What minimum acceptable, or breakeven, price of gold would be required to economically justify the extraordinarily high level of investment in gold exploration in recent years? In other words, what gold price would be needed to give a 10-percent rate of return on investment? The idea behind making this type of assessment is that it should be somewhat less difficult to make a meaningful judgement concerning which side of the breakeven point the uncertain future gold price will be on than to provide a more specific prediction.

The breakeven gold price results for Australia, Brazil and Canada, presented in Table 9, provide a further measure of the competitive position of these three major gold producing nations in the international gold market.

The main comparative findings can be summarized as follows:

- for the overall study period, gold exploration in Brazil is found to have the lowest breakeven gold price requirement;

Table 9. Breakeven gold price requirement

Country	Period	Breakeven Price ($ per ounce)
Australia :	1969-82	340
	1983-86	343
	1969-86	342
Brazil :	1969-82	224
	1983-88	378
	1969-88	291
Canada :	1969-82	395
	1983-88	665
	1969-88	508

- Australia, unlike Brazil and Canada, has been able to maintain essentially the same minimum acceptable price between the first and second intervals, thereby improving its relative position with time;[31]
- the breakeven price findings again leave little doubt that gold exploration in Canada has been an uneconomic endeavour overall, particularly during the 1983-88 interval;
- Brazil's competitive position is further strengthened by the opportunity to sell gold at the parallel-market price, requiring correspondingly lower international prices than the breakeven values shown in Table 9.

[31] The second interval in Australia ends in 1986, thus excluding the two years of maximum exploration expenditures in 1987 and 1988.

Summing Up

The average undiscounted exploration expenditure per economic discovery in Australia and Brazil ($13 million and $17 million respectively) is found to be only about one-quarter of the average discovery cost in Canada ($67 million). Economic gold deposits in all three countries clearly represent worthwhile exploration targets. The economic discoveries in Australia and Brazil are shown to be somewhat more profitable than those found in Canada to date. On the other hand, economic gold deposits in Brazil and Canada are characteristically much larger than those discovered in Australia.

The bottom-line expected value results demonstrate that gold exploration in Australia and Brazil is a wealth-creating activity, offering potential to increase substantially the economic surplus available to society. For example, the expected rate of return for exploration is 18 percent in Australia and 19 percent in Brazil. Conversely, gold exploration in Canada is found to be a

strongly uneconomic activity overall, yielding an expected rate of return of only 4 percent relative to the 10-percent hurdle rate. This negative performance is mainly attributable to the very high average discovery cost.

Time trends in the three countries are also examined, comparing the performance of gold exploration during the 1969-82 interval with the more recent gold rush from 1983. The economic potential of gold exploration in Australia has held up relatively well with time, a sharp improvement in typical discovery costs tending to offset a strong decline in the average size of the economic deposits found. The reliability of the changes assessed in Brazil is limited by the small sample size of exploration experience in the 1969-82 interval. Discovery of the four largest economic gold deposits at this time precipitates a steep fall in the economic potential of Brazilian gold exploration to near the breakeven point during 1983-88. In Canada, a three-fold increase in the cost of discovering an economic deposit from 1969-82 to 1983-88 drives the viability of gold exploration far below the economic margin despite favourable trends in the return characteristics of the economic deposits found.

Finally, a related question is addressed for each of these three nations: What minimum acceptable, or breakeven, price of gold would be required to economically justify the extraordinarily high levels of gold exploration in recent years? For the overall study period, gold exploration in Brazil is found to have the most competitive breakeven price requirement ($291 per ounce). However, Australia's position improves with time, requiring the lowest gold price during the most recent interval ($343 per ounce). Brazil's international ranking is further strengthened by the opportunity to realize the parallel-market premium on gold sales. The breakeven price findings for gold exploration in Canada, $508 per ounce for the 1969-88 period, including $665 per ounce for the 1983-88 interval, once more point to the uneconomic, wealth-destroying character of this endeavour from a national perspective.

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Appendix I

Historical Statistics

Table 10. International gold price

Year	Average Annual Gold Price (current US $/oz)	United States Consumer Price Index (1985 = 100)	Inflation Multiplier (1990 = 1.000)	Average Annual Gold Price (constant 1990 US $/oz)
1969	41.06	34.08	3.563	146.30
1970	35.93	36.09	3.365	120.89
1971	40.80	37.62	3.228	131.69
1972	58.16	38.87	3.124	181.69
1973	97.33	41.28	2.942	286.31
1974	159.26	45.84	2.649	421.88
1975	161.02	50.03	2.427	390.82
1976	124.84	52.90	2.295	286.57
1977	147.72	56.33	2.156	318.44
1978	193.23	60.63	2.003	387.00
1979	306.69	67.47	1.800	551.97
1980	612.56	76.58	1.586	971.31
1981	459.72	84.48	1.437	660.79
1982	375.79	89.68	1.354	508.83
1983	424.18	92.57	1.312	556.42
1984	360.44	96.56	1.258	453.27
1985	317.27	100.00	1.214	385.26
1986	367.51	101.86	1.192	438.12
1987	446.47	105.67	1.149	513.06
1988	437.05	109.91	1.105	482.86
1989	381.43	115.21	1.054	402.02
1990	384.05	121.43	1.000	384.05

Sources: prices from *Metals Week*; consumer price index from *International Financial Statistics*, International Monetary Fund, Washington.

Table 11. Gold mine production (tonnes)

	Australia	Brazil	Canada	South Africa	United States	Other Countries	Total
1969	22	9	79	973	54	115	1,252
1970	19	9	75	1,000	54	116	1,273
1971	21	9	71	976	47	109	1,233
1972	18	10	65	910	45	129	1,177
1973	17	11	61	855	37	130	1,111
1974	16	14	53	759	35	119	996
1975	16	14	51	713	33	119	946
1976	16	14	53	713	33	135	964
1977	19	16	54	700	34	139	962
1978	20	22	54	704	41	141	972
1979	19	35	51	703	40	131	969
1980	17	40	51	673	30	156	967
1981	18	42	52	656	43	181	992
1982	27	45	65	623	46	235	1,041
1983	34	70	74	678	62	209	1,127
1984	40	62	84	680	65	243	1,174
1985	57	73	88	671	75	282	1,246
1986	75	84	105	638	116	295	1,313
1987	108	91	115	605	154	323	1,396
1988	157	112	128	618	189	269	1,472
1989	172	108	158	606	259	264	1,567
1990	208	119	172	609	301	286	1,695
Total	1,116	1,009	1,759	16,063	1,772	4,127	25,845

Source: annual gold reviews, Consolidated Gold Fields, see Murray *et al* (1990, 1991).

Table 12. Gold exploration expenditures in the Western World (1990 US$ millions)

	Australia	Brazil	Canada	South Africa	United States	Other Countries	Western World
1969	19	0	35	12	28	5	99
1970	26	1	35	16	33	6	116
1971	25	1	28	17	38	6	115
1972	17	1	20	9	37	4	89
1973	14	2	30	10	57	6	118
1974	15	3	32	9	72	7	138
1975	14	5	41	15	75	8	158
1976	13	19	35	17	92	9	185
1977	19	17	48	22	117	19	242
1978	27	19	63	22	131	23	285
1979	53	14	77	22	165	29	358
1980	82	18	129	28	230	66	554
1981	129	37	195	36	278	59	734
1982	141	55	189	45	245	75	751
1983	153	40	192	47	227	73	732
1984	208	77	205	140	255	132	1,017
1985	208	64	328	148	191	347	1,285
1986	304	62	475	170	178	418	1,606
1987	450	58	933	190	225	464	2,321
1988	460	72	890	224	371	504	2,522
1989	325	75	558	266	232	485	1,941
1990	260	46	429	242	160	379	1,516
Total	2,963	685	4,968	1,707	3,435	3,125	16,883

Main sources:

Australia: Australia Bureau of Statistics, Western Mining Corporation;
Brazil: Mackenzie and Doggett (1991);
Canada: Energy, Mines and Resources Canada, D. Cranstone; Centre for Resource Studies;
South Africa: Handley (1990), Beukes (1988);
United States: D. Silver, Schreiber and Emerson (1984).

Appendix II

Possible Economic Discoveries for Evaluation

Table 13. Possible economic discoveries for evaluation in Australia, 1969-86

1969-82

Ajax	Defiance	Peak
Argo	Emu South	Starra
Badgebup	Hannan's South	TC-8
Cork Tree Well	Hedges	Telfer
	Orchin	Victoria

1983-86

Bardoc	Goodall	Pajingo
Beasley Creek	Granny Smith	Panglo
Belyando	Henty	Reedy North
Blue Funnel	Higginsville	Revenge
Bottle Creek	Jasper Hills	Roebourne
Bounty	Johnston Range	Scotia
Britannia	Junction	Temora
Bullabulling	Lady Gladys	Thiel Well
Bulls Pinnacle	Lady Bountiful Extended	Tom's Gully
Callion	Lancefield Deeps	West Black Flag
Cave Rocks	Lucky Draw	White Devil
Dobroyde	Mount Wilkinson	White Flag
Far Fanning	Mount Gibson	Wirralie
Forrestania	Nagambi	Yandan
Golden Kilometre	Orion	Yundamindera

Table 14. Possible economic discoveries for evaluation in Brazil, 1969-88

1969-82

Cerrito do Ouro	João Ricardo de Souza	Paru-Ipitinga
Crixás	Lagoa Seca	Pompex-Crixás II
Fazenda Brasileiro	Luziania	Serra Pelada
Ibiajara	Morro do Ouro	

1983-88

Antas	Guapore Primary	Mina Nova Sul
C 1	Igarapé Bahia	Posse
Cabacal	Itabira	Riacho dos Machados
Cachoeira II	Jenipapo	Salamangone
Cachoeira I	João Belo	São Francisco
Caeté - Roco Grande	Lourenco Primary	Tartarugalzinho
Case de Pedra (Cuiaba)	M 11	Zacarias
Corrego de Sitio	Mari	

Table 15. Possible economic discoveries for evaluation in Canada, 1969-88

1969-82

Aquarius	Doyon	Norbeau
Augmitto	Dumont	Norlartic
Baker	Ellison	North Pascalis
Blackdome	Erickson	Opapamiskan
Beacon	Ferderber	Orenada 4
Bell Creek	Frankfield	Puffy Lake
Big Missouri	Golden Bear	QR
Bousquet	Gold Pond	Reg
Bullmoose	Gwillam	Ren
Cameron Lake	Harrison Lake	Richfield
Canty	Hemlo	Rio (Flin Flon)
Cape Spencer	Heva	Romfield
Cape Ray	Highland Crow	SB
Caribou	Hoyle Pond	Scadding
Carolin	Lawyers	Shoal Lake
Carshaw	Mascot (Nickel Plate)	Sleeping Giant
Chadbourne	McBean	St. Andrews
Chester	McDermott	Star Lake
Cinola	Montauban	Tillicum
Cochrane Hill	Mount Skukum	Toodoggone (Energex)
D'Estor	New Pascalis	Wedge Lake
Detour Lake	Nighthawk Lake	Weedy Lake

1983-88

Astoria	Fontana	Margaret Extension
Aylwin	Garrison	Ming's Bight
Bakos	Glimmer	Montauban South
Bannockburn	Golden Patricia	Moss Lake
Bousquet II	Goldwedge	Mouska
Brookbank	Gracie	Murray Brook Gold
Burnt Timber	Horseshoe	Nicholas Lake
Chetwynd	Indin Lake	Nugget Pond
Clavos	Jackson's Arm	Pelletier
Colomac	Jasper	Porcher Island
Congress	Joe Mann Est	Remnor West
Courageous Lake	Ketza	Ronnoco
Creek Zone	Kierans	Silbak
Devil's Cove	Kremzar	Silidor
Dome Mountain	Lac Rouleau	Snip
Dona Lake	Lightening	Springpole
Duquesne	Little Stull	Sulpherets
Eagle River	Magino	Tangier
Eastmain	Magnacon	Tartan Lake
Eskay	Mahogany (Jolu)	Tower Lake East
Farley		Vezza

Appendix III

Economic Potential of Gold Exploration

Table 16. International comparison: before-tax cash flow characteristics and expected value for an economic deposit at expected prices

Characteristic	Australia 1969-88	Brazil 1969-88	Canada 1969-88
Total exploration expenditures ($ million)	526	338	2,899
Number of economic deposits	42	23	43
Time periods (years)			
Exploration	3	3	13
Development (maximum)	3	3	3
Production (maximum)	33	39	30
Overall	37	43	44
Undiscounted values ($ million)			
Revenue	182	495	406
Exploration expenditure	13	17	67
Development capital cost	22	28	39
Production cost	91	249	198
Cash flow	56	201	102
Economic indicators – start of development			
Net present value ($ million)	28	57	44
Rate of return (percent)	39	38	29
Economic indicators – start of exploration			
Average exploration expenditure (E, $ million)	11	14	36
Average return (R, $ million)	23	42	12
Expected value (EV, $ million)	12	28	-24
Expected rate of return (percent)	18	19	4

Table 17. International comparison: before-tax cash flow characteristics and expected value for an economic deposit at lower-limit prices

Characteristic	Australia 1969-88	Brazil 1969-88	Canada 1969-88
Total exploration expenditures ($ million)	526	338	2,899
Number of economic deposits	12	8	15
Time periods (years)			
Exploration	9	10	39
Development (maximum)	2	3	3
Production (maximum)	17	30	30
Overall	27	41	70
Undiscounted values ($ million)			
Revenue	253	369	623
Exploration expenditure	44	48	193
Development capital cost	35	33	65
Production cost	151	144	363
Cash flow	23	144	2
Economic indicators – start of development			
Net present value ($ million)	20	58	33
Rate of return (percent)	22	37	18
Economic indicators – start of exploration			
Average exploration expenditure (E, $ million)	32	30	55
Average return (R, $ million)	8	23	0
Expected value (EV, $ million)	-24	-7	-55
Expected rate of return (percent)	2	8	0

Table 18. International comparison: before-tax cash flow characteristics and expected value for an economic deposit at upper-limit prices

Characteristic	Australia 1969-88	Brazil 1969-88	Canada 1969-88
Total exploration expenditures ($ million)	526	338	2,899
Number of economic deposits	58	30	94
Time periods (years)			
Exploration	2	3	6
Development (maximum)	3	3	3
Production (maximum)	33	39	30
Overall	36	43	37
Undiscounted values ($ million)			
Revenue	182	553	335
Exploration expenditure	9	13	31
Development capital cost	16	24	31
Production cost	65	199	134
Cash flow	92	317	139
Economic indicators – start of development			
Net present value ($ million)	47	97	54
Rate of return (percent)	76	64	39
Economic indicators – start of exploration			
Average exploration expenditure (E, $ million)	7	11	19
Average return (R, $ million)	40	76	29
Expected value (EV, $ million)	33	65	10
Expected rate of return (percent)	38	31	13

Table 19. International comparison: time trends in before-tax cash flow characteristics and expected value for an economic deposit

Characteristic	Australia		Brazil		Canada	
	1969-82	1983-86	1969-82	1983-88	1969-82	1983-88
Total exploration expenditures ($ million)	253	273	98	290	772	2,127
Number of economic deposits	11	31	7	16	23	20
Time periods (years)						
Exploration	5	2	3	3	7	21
Development (maximum)	3	2	3	4	3	3
Production (maximum)	33	19	33	39	30	17
Overall	39	22	37	44	38	39
Undiscounted values ($ million)						
Revenue	370	115	1,140	213	563	226
Exploration expenditure	23	9	14	18	34	106
Development capital cost	42	15	47	19	50	26
Production cost	178	60	561	113	284	99
Cash flow	127	31	518	63	195	-52
Economic indicators – start of development						
Net present value ($ million)	56	18	137	23	49	39
Rate of return (percent)	37	42	42	33	24	40
Economic indicators – start of exploration						
Average exploration expenditure (E, $ million)	18	8	12	15	24	43
Average return (R, $ million)	36	16	105	16	26	5
Expected value (EV, $ million)	18	8	93	1	2	-38
Expected rate of return (percent)	16	19	28	11	10	0

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